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ORGANIC DEPOT WARRANTIES FOR AIRCRAFT
INERTIAL NAVIGATION SYSTEMS

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LSSR 38-77B

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The objective of this research was to develop a methodology for applying a warranty concept to an organic depot workload with the potential of increasing operational reliability and decreasing life cycle costs. To establish the basic methodology, research questions were formulated to address four key concepts required to develop a warranty methodology for aircraft inertial navigation systems repaired by the Aerospace Guidance and Metrology Center. While this study concentrated on these systems, the techniques employed were applicable to any organic depot workload meeting the criteria indicated in the study. Based on the results of analyzing the research questions it was concluded that a basic methodology must encompass a criteria test to screen potential candidates, and the reliability probability distribution should be determined to assist in reducing the uncertainty in the management decision process. It was also concluded that the DMS, AFIF procedures provide sufficient flexibility to permit the application of an organic warranty. Finally, a possible approach to a warranty application was demonstrated. The research concluded that an organic depot warranty is feasible and provides the potential for reducing logistic support costs by directing management attention to those units returned to the depot, but not requiring repair.

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ORGANIC DEPOT WARRANTIES
FOR
AIRCRAFT INERTIAL
NAVIGATION SYSTEMS

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

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In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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CHAPTER I

INTRODUCTION

STATEMENT OF THE PROBLEM

The Department of Defense annually allocates billions of dollars to the maintenance of its weapon systems. The increased reliability and maintainability of these weapon systems have been recognized as important determinants in optimizing the amount of national defense obtained from the available dollars (3:1). One method of increasing the reliability of weapon system components, which has recently received increased emphasis, is the use of reliability improvement warranties as part of the system procurement process. The goal of these warranties is to provide profit or loss incentives to the contractor to produce more reliable equipment which will, in turn, reduce life cycle costs. While the application of reliability improvement warranties to newly procured systems offers the distinct possibility of reducing future operation and support costs, effort needs to be directed to reducing the operation and support costs of systems already in use. The current emphasis in the Department of Defense for reducing operation and support costs highlights the immediate need for new management techniques to improve operational reliability while expending minimum dollar resources.

The fundamental problem to be addressed in this research is can a reliability improvement warranty concept be applied to systems already in use by the military and repaired in organic facilities to decrease present operation and support costs?

BACKGROUND

Evolution of the Reliability Improvement Warranty Concept

In an era of inflationary prices and costs, the Department of Defense has been faced with the perplexing problem of acquiring complex weapon systems while receiving a smaller percentage share of the federal budget and the nation's gross national product (24:108). This problem has been further compounded by the rising costs of operating and maintaining these systems. Major General Robert F. Trimble, former Air Force Director of Procurement Policy, defined the problem and a possible solution in an address to a Naval Aviation Supply Office Seminar on warranties when he stated:

> The Department of Defense is faced . . . [with a problem] . . . in attempting to procure the sophisticated equipment we need to defend our country. There is no way . . . to match currently planned equipment costs and still retain technological superiority in all our forces. As an example, in fiscal year 1964, the Air Force operation and maintenance costs accounted for \$4.3 billion out of a total obligational authority of approximately \$20 billion [21 percent]. However, in fiscal year 1973, Air Force operation and maintenance costs totalled \$6.7 billion out of \$24.8 billion [27 percent]. Thus, it is apparent that operation and

maintenance costs, which are projected to continue to grow at an increased rate, are taking an increasingly larger percentage of our defense dollars. This means that we must place greater stress on increasing equipment field reliability in order to get the best overall defense for the dollars available [22:n-i].

General Trimble's comments were substantiated by several studies conducted by the Office of the Assistant Secretary of Defense for Research and Engineering (7; 37). These studies separately concluded that the desired operational reliability was not being designed into new electronic systems, and, as a result, life cycle costs were increasing due to excessive equipment failure rates. In an effort to reverse this trend, the Department of Defense decided to explore the possibility of employing an acquisition strategy used successfully by the commercial airlines in which the contractor warranted the operational reliability of a system for a specified period after acquisition (37:14). The driving motivation in this technique was that the contractor agreed to repair all failures encountered as part of a fixed price contract for the system procurement and repairs. Thus, the contractor's final profit or loss incurred was determined by the number of failures and by the costs incurred to repair the failed items. If the system performed better than anticipated, the repair costs were decreased, and the contractor's profit was increased. If the system performed less effectively than anticipated, the repair costs increased, and the contractor's profit was

reduced or eliminated. By employing this acquisition strategy, it was believed that the following benefits would accrue:

1. Improved equipment reliability.
2. Reduced life cycle costs because of increased reliability.
3. Increased incentive to the contractor to design for support rather than designing for lowest procurement cost.
4. Controllable life cycle costs as a result of predictable failure rates [2:v-vi].

As these benefits were compatible with the reliability improvement and cost reduction goals set by the Department of Defense, it became apparent that this acquisition strategy, known as reliability improvement warranty (RIW), had direct application possibilities for Department of Defense procurements. Jacques S. Gansler, then Assistant Director for Electronics in Defense Research and Engineering, noted in a 1973 speech:

> It should be clear that . . . our cost and reliability problems are taking us more in the direction of commercial practices. The transition is not one from total military performance-oriented thinking to total commercial price-oriented thinking; rather, it is a change from performance only to the addition of cost and reliability to major design criteria [37:14].

Conceptual Definitions

Before proceeding further, it is appropriate that conceptual definitions be established for the key points considered in this research.

Reliability. While reliability has various connotations, the most generally accepted definition is that reliability

is "the probability that a device will operate adequately for a given period of time in its intended application [1:1]." This definition directly interfaces with the RIW concept in that reliability is measured by the length of time of operation of a system before failure within established parameters of what a reportable failure is (1:2). To effectively apply the RIW concept to a given system, the failure parameters must be explicitly defined (2:xiii).

Reliability measurement. The measure of operating time between failure must also be precisely defined. The most commonly used factor is the mean time between failure (MTBF) which is calculated by dividing the weapon system's operational hours (usually flying hours per month) by the number of times the system was removed due to failure [as reported in the Air Force Manual 66-1 Maintenance Management System (31:A3-9)]. Reliability operating time may also be determined in terms of time between overhaul (TBO) which can be calculated for systems having elapsed time indicators (ETI) which record the actual hours the system is operated. When the ETI readings are recorded after each depot level repair and each failure requiring depot level repair, the TBO may be computed (30:4).

Life cycle costs. The RIW concept is designed to reduce life cycle costs and thereby reduce budgeted operation and maintenance expenditures. Life cycle costs have been

defined as "the total cost to the Government of acquisition and ownership of . . . equipment over its full life [34:1-336.1]." Life cycle costs are important in evaluating the cost effectiveness of a system in that over the total life of a system, these costs can become substantial due to excessive operation and maintenance expenditures. Therefore,

> It is essential that such costs be considered in development and acquisition decisions in order that proper considerations can be given to those systems . . . that will result in the lowest life cycle cost to the Government [34:1-336.1].

RIW. The RIW concept has been defined by the Air Force Directorate of Procurement Policy (AF/LGP) as:

> . . . a provision in either a fixed price acquisition, or fixed price equipment overhaul contract in which:
> (a) the contractor is provided with a monetary incentive, throughout the period of the warranty, to improve the production design and engineering of the equipment so as to enhance the field/operational reliability and maintainability of the system/equipment; and
> (b) the contractor agrees that, during a specified or measured period of use, he will repair or replace (within a specified turnaround time) all equipment that fails (subject to specified exclusions, if applicable) [29:5-6].

From this definition it can be seen that the basic objective of an RIW is to motivate contractors to design and produce systems having low repair costs and low failure rates. The typical RIW contract provides that the contractor will repair or replace failed units within a specified period (turnaround time), and that the contractor will enhance the operational characteristics (reliability) through no cost engineering change proposals.

> Once a fixed price is established for the RIW, the level of profit realized . . . is dependent upon the equipment's reliability . . . , which in turn is influenced by any improvements that . . . [the contractor] . . . can make . . . to reduce the rate of returns . . . and the cost of such repairs [14:4-19].

Thus, the contractor has a direct financial stake in the field performance of the item, and he can no longer seek the lowest acceptable reliability and lowest production cost [14:4-20].

<u>RIW Applications</u>

The application of the RIW concept to procurement actions provides the baseline for the potential development of an organic depot warranty. The basic RIW criteria are discussed in the following paragraphs.

<u>System selection criteria</u>. While the inherent advantages of using an RIW to reduce life cycle costs appear to be applicable to virtually any system, Balaban and Retterer caution that they cannot be used in every case (2:xx). In fact, "attempts to 'force fit' the concept can only create difficulties [2:xx]" if certain criteria are not met. Dunn and Oltyan noted that an RIW application should encompass the following criteria:

1. Use of a firm-fixed price contract to achieve maximum motivation.
2. Use of a multi-year contract is essential to allow for reliability growth and analysis of failure trends.
3. Ease of transportation to facilitate returns to the repair activity and to reduce the need for spare units through compressed pipeline time.

4. Use of an elapsed time indicator to document the actual operating hours per unit.
5. A large initial procurement in terms of the number of units purchased and the purchase price.
6. Self-containment of the unit to assist in failure analysis [8:47-67].

Balaban and Retterer suggest that the following additional criteria be considered:

1. The unit should be field-testable.
2. Specific knowledge concerning the unit application in terms of expected operating time and the use environment is necessary.
3. The product must be sufficiently developed that reasonable estimates of the expected reliability and maintainability may be made [3:61].

While each of these criteria need not be satisfied totally before considering an item for RIW application, they should be considered as an initial screening device (2:xvi).

Types of RIW. The RIW concept can be implemented in two basic manners: an RIW for a specified period of time or an RIW with a MTBF guarantee. When the RIW is employed without the MTBF guarantee, the contractor agrees to perform repair services on the equipment for an extended period at a fixed total price. The contractor is responsible for the repair of all failed items for the extended period which may be measured in time (months or years) from first delivery or total operational hours. This type of RIW is best implemented as part of the production contract as the reliability improvements should begin as soon as operational characteristics of the system are determined (2:2-5).

The RIW with a specified MTBF was initiated by the commercial airlines to provide definitive criteria for establishing operational reliability. If the equipment does not meet the specified MTBF objective, the contractor is not only penalized by higher costs, but additional spare units must also be provided by the contractor to maintain operational effectiveness. As this RIW approach is dependent upon the accumulation of voluminous data to support the MTBF computations, it is somewhat more costly to administer. It does, however, provide greater insight into failure trends and therefore is the preferred method of application (2:2-7).

<u>RIW uses</u>. Although the RIW concept is a recent innovation in the Department of Defense procurement field, there have been several applications which have supported the basic premise of increased reliability and decreased life cycle costs. The most conclusive example of the advantages of the RIW concept was demonstrated by the U. S. Navy and Lear-Siegler, Inc. RIW contract for gyro repair. When the RIW contract was initiated in 1968, the MTBF for the gyro was approximately 400 hours. Under the terms of the RIW contract, Lear-Siegler agreed to increase the operational reliability to 500 hours MTBF at a total cost of $3 million. At the conclusion of the contract period, the MTBF had increased to 531 hours, and the Navy estimated that net cost savings as a result of the increased reliability were

approximately $2 million (17:7). Based on this contract and several subsequent applications, the Naval Aviation Supply Office concluded that "reliability improvement warranty does in fact decrease life-cycle costs [17:8]."

The Air Force has also implemented the RIW concept on a limited basis, and although the final results have not yet been determined, there are indications of "beneficial results [14:4-25]."

Organic Depot Maintenance

The Air Force has developed an organic depot level maintenance capability to support mission essential materiel which requires continuing depot level repair to sustain military operations under emergency or wartime conditions or in peacetime, to assure operational readiness (36:2). Organic depot level maintenance is accomplished at the five Air Logistic Centers (Ogden, Oklahoma City, Sacramento, San Antonio, and Warner-Robins) and the Aerospace Guidance and Metrology Center, Newark AFS, Ohio. These activities, which are under the management of the Air Force Logistics Command, provide Air Force and interservice depot level maintenance for aircraft repair and modification, engine overhaul, repair and overhaul of exchangeable items, and missile repair or modification (28:1).

The Air Force organic depots are operated as part of the Depot Maintenance Service, Air Force Industrial Fund (DMS, AFIF). The DMS, AFIF is a revolving fund used to

finance the cost of depot level repair by billing customers for repair work performed. As a revolving fund, the DMS, AFIF is designed to be a non-profit or loss operation with the "charges . . . designed to reimburse the DMS, AFIF for costs incurred in rendering depot maintenance [28:1]." During fiscal year 1976, these activities provided depot level repair services valued at $1.1 billion out of a total Air Force depot repair outlay of $1.5 billion. Exchangeable item repair constituted $567 million (55 percent) of the organic depot expenditure (19).

PROBLEM JUSTIFICATION

As a result of the breakeven constraints imposed by the DMS, AFIF and the lack of direct competition for workloads allocated to organic depots, there has been some criticism leveled at the efficiency of government depots and their ability to produce a reliable product (11:1). The Department of Defense has placed considerable emphasis on achieving economies in obtaining repair services from the private sector, but there has been little direct, detailed examination of the potential for applying warranty type provisions to organic depot workloads. A survey of current literature does, however, indicate that the Navy is exploring the use of RIW-type provisions for selected items repaired at the Naval Air Rework Facilities at Pensacola, Florida, and North Island, California. While the final

results of these applications are not yet complete, there are indications of positive results in reducing costs and improving reliability (5; 15).

The possibility of applying warranty type provisions to organic depot workloads has also been explored by the Plans and Programs Office (XRX) at the Air Force's Aerospace Guidance and Metrology Center (AGMC), Newark AFS, Ohio. A study prepared by Don E. Hunt of AGMC/XRX indicated that:

> . . . government depots are rich in management, maintenance, and engineering talents and skills. They also have extensive investments in facilities and equipment devoted to the testing, maintenance, and repair of weapon systems. It would seem that this environment could be conducive to the productive use of the warranty concept [13:2].

Additional research has been conducted at AGMC by Russell Genet and Theodore Crosier as to the potential use of warranties at government depots. They concluded that the customer of the depot could potentially benefit from a warranty application through stabilized budget planning, decreased costs, and increased reliability (9:10).

While these studies have hypothesized the use of warranty concepts for organic depots, they have not decisively presented a viable method of implementing or using an organic depot warranty. Additionally, the funding considerations dictated by the DMS, AFIF have not received adequate analysis.

OBJECTIVE

The overall objective of this study was to develop a methodology for applying a warranty concept to an organic depot workload with the potential of increasing operational reliability and decreasing life cycle costs.

SCOPE

The basic premise for this research was the conclusion reached by Hughes Aircraft researchers working under Air Force contract to study warranty applications. Their conclusion indicated "that sealed, Air Force depot/supplier repairable, high dollar value, low mean time between failure units were most amenable to Air Force avionic guarantee applications [6:235]." In consonance with this conclusion, this study concentrated on the potential application of warranty concepts to inertial navigation systems repaired by AGMC. While this effort was restricted to those systems repaired by AGMC, the potential exists for additional applications if the criteria stated in this research are met.

This research did not attempt to address the question of allocating workloads between contractor and organic depot facilities on the basis of mission essentiality (36). A given assumption in this research effort was that organic depots will remain an essential part of the overall depot maintenance concept, and that certain mission

essential workloads will continue to be allocated to organic depot facilities.

Additionally, the research was restricted to aircraft inertial navigation systems repaired at AGMC because of the security classification of missile (Minuteman and Titan) inertial navigation reliability assessments. The study also assumed that the funding constraints imposed by the DMS, AFIF cannot be changed.

RESEARCH QUESTIONS

To achieve the objective of this research, the following questions were considered:

1. Do inertial navigation systems repaired at AGMC meet the basic RIW application criteria as established by Dunn and Oltyan, and Balaban and Retterer?

2. Do inertial navigation units fail in conformance with recognized reliability probability distributions? If so, could these distributions be used as the basis for building a warranty application methodology?

3. Do Depot Maintenance Service, Air Force Industrial Fund procedures provide sufficient flexibility to accommodate warranty cost considerations and visibility?

4. Would the development of an organic depot warranty methodology enhance the potential for decreased operation and support costs and increased reliability?

CHAPTER II

METHODOLOGY

BACKGROUND

The rationale for considering the application of a warranty concept to organic depot workloads was presented in Chapter I along with the basic research questions which must be answered to establish a methodology for the organic depot warranty application. This chapter develops the methodology necessary to address the research questions in a meaningful manner. Each research question will be presented in an additional section of this chapter in a more specific context relative to the potential organic depot warranty application. Specific analysis techniques and criteria will be presented for each question, and data sources and requirements will be identified. Each section will also enumerate the specific assumptions and limitations relative to each question. However, before proceeding to the specific research questions and their associated tests and analysis, the population and variables under examination must be defined.

Population Definition

A population may be defined as "each and every member of some group [4:8]." The population considered by

this study was the aircraft inertial navigation systems repaired at the Aerospace Guidance and Metrology Center (AGMC), Newark AFS, Ohio. The elementary units of the population were described as specific inertial navigation units identified to their particular weapon system and further limited to specific serial number identification. Table 1 details the aircraft inertial navigation systems repaired at AGMC as of 31 December 1976.

Variable Definition

The specific characteristics of an item or process under observation may be considered as variables. For purposes of this study, the primary variable was the time between overhaul (TBO) for a sample of inertial navigation systems from a weapon system. The TBO was computed by comparing the elapsed time indicator (ETI) reading of specific serially numbered units at the time they were repaired by the depot to the ETI reading for that unit when it was returned to the depot for repair. The ETI recorded the number of hours that a particular system was operated, and by comparing the out and in readings, the number of operational hours before a depot repair failure occurred was calculated. ETI readings are recorded for each unit repaired at AGMC by the production scheduler when the unit is shipped to the field as a serviceable unit and when the unit returns for repair. Data were gathered for a sample

Table 1

AGMC WORKLOADS

INERTIAL SYSTEM	WEAPON SYSTEM	UNIT COST	INVENTORY	FY 77 REPAIR PRICES PER UNIT	FY 77 WORKLOAD	FY 77 TOTAL REPAIR COST	ALC ITEM MANAGER
N-16	FB-111	$331,000	318	6,299	160	$1,007,840	SM-ALC
LN-12	F-4	36,000	2,676	3,869	2,394	9,262,385	OC-ALC
LN-14	F-111A	39,000	397	3,223	273	879,879	SM-ALC
LN-15	B-52G	64,000	375	2,956	258	762,648	OC-ALC
KT-71	F-105D	60,000	62	3,513	36	126,468	OC-ALC
KT-73 (Air Force)	A-7D	54,000	593	3,202	449	1,437,698	OC-ALC
KT-73 (Navy)	A-7E	54,000	586	3,171	360	1,141,560	ASO
KT-76	SRAM*	40,000	1,533	3,806	104	395,824	OC-ALC
FLIP	C-5A	253,000	138	10,741	168	1,804,488	SA-ALC

*considered an aircraft system because of similarity to KT-73

Source: AGMC/ACD
Data as of 31 December 1976

of serially numbered units from an inertial navigation system meeting the criteria established by Research Question 1. TBO was considered a discrete variable at the ratio level.

Additional variables considered in this research effort were the type of repair afforded particular serially numbered systems, the characteristics of the particular systems, and the costs of repair based on the appropriate fiscal year's repair price per unit. The type of repair was defined as a discrete variable at the ordinal level. The characteristics of particular systems were classified as discrete variables at the nominal level, while repair costs were considered as discrete variables at the interval level.

Sampling Definition

"Once the population has been defined, a sample can be described as some of the members of the population [4:9]." Although various methods exist for selecting samples from a population, random sampling is generally the preferred technique because random sampling lends itself to describing probability models for most distributions from which generalizations concerning the population can be drawn (12:117).

Random sampling was used in this research to select serially numbered units from the inertial navigation system identified as meeting the selection criteria set forth in Research Question 1. The sample was drawn from a population

of units repaired by AGMC during 1975 and 1976 and was used as the data base for the reliability assessment in Research Question 2. A pilot study conducted by the researchers in February 1977 indicated that a sample size of 100 units would be required. A detailed approach to random sample selection and application is presented in Air Force Audit Agency Regulation 176-116 (33). The procedures contained in this regulation were used to select the sample from the finite population of the units repaired in 1975 and 1976. Sampling without replacement techniques was utilized.

OVERVIEW OF METHODOLOGY

Before proceeding to the detailed analysis of the research questions and the techniques which were used to address the questions, a brief overview of the methodology employed is appropriate.

The first step in this analysis was to determine if the aircraft inertial navigation systems repaired at AGMC meet the basic RIW application criteria established by Balaban and Retterer (3), and validated by Dunn and Oltyan (8). While these criteria were established for systems being procured by the Department of Defense, it was assumed that those criteria relating to equipment and operational factors would be appropriate for systems already in use. From those systems meeting the basic application criteria, a system was selected for further study.

The second step in this research was to determine if a random sample of failed units from the inertial navigation system selected could be fitted to a known probability distribution. The determination of a fit to a known probability distribution permitted the prediction of expected failure rates based on given population parameters (mean and variance). The estimation of failure rates for a given system is a basic requirement for establishing a warranty policy. As part of this analysis, consideration was given to failures by type of repair afforded the unit when repaired and when returned. A pilot study conducted by the researchers in February 1977 indicated that the TBO of failed KT-73 inertial navigation units followed a negative exponential distribution.

The third step in establishing an organic depot application methodology was to determine what cost considerations can be established within the DMS, AFIF framework. This evaluation was conducted by discussing possible costing techniques with appropriate DMS, AFIF management personnel at AFLC and AGMC.

The final step in this research was to evaluate the effectiveness of the potential application of an organic depot warranty to the inertial navigation system selected. This evaluation was accomplished by the application of a mock warranty to the selected units and the determination of annual depot maintenance costs through the use of the

AGMC Life Cycle Cost Model. Through this procedure, the potential cost savings of the application of an organic depot warranty were evaluated.

RESEARCH QUESTION ANALYSIS

This section describes the specific analysis techniques which were used to answer the research questions formulated in Chapter I.

Research Question 1

> Do inertial navigation systems repaired at AGMC meet the basic RIW application criteria as established by Dunn and Oltyan and Balaban and Retterer?

Background. Dunn and Oltyan's research of reliability improvement warranty (RIW) applications in procurement actions concluded that several criteria must be met for an item to be considered for RIW (8:63). Assuming that these criteria would also be applicable to an RIW-type organic depot warranty, it is appropriate that a system under consideration for an organic warranty should also meet this criteria. Dunn and Oltyan concluded that:

> . . . a potential RIW candidate should come from an initial population of at least 100 items. The individual cost per item should be at least $1,000 . . . . The packaged item should be no larger than 15 cubic feet and weigh less than 350 lbs. If the item is presently in the inventory, it should be repaired at the depot in 80% or more of the instances in which it fails. The item should be self-contained in that when a failure occurs, only the item covered by the RIW need be returned to the contractor. An ETI is helpful in administering the contract when the contract specifies

a nominal cumulative hourly limit, but not essential. The RIW contract should be firm-fixed price, capable of being structured under a multi-year arrangement. Finally, the warranty period should be long enough to cover three failure cycles of the item [8:63-65].

Balaban and Retterer also established application criteria in their evaluation of RIW applications to Air Force electronic systems. Their application criteria were established in the form of an application-criteria matrix which divided the application criteria into three areas: procurement factors, equipment factors, and operational factors. For each area, an importance factor was assigned as follows:

1. Major. Failure to meet any of the stated criteria could be grounds for not using warranty.
2. Secondary. Failure to meet a stated criterion will generally not be a sufficient basis for rejecting warranty, but a number of such failures could be.
3. Minor. Failure to meet one or more of these criteria is generally not considered serious but may require special considerations in structuring the warranty contract or administrative procedures [2:3-4].

However, Balaban and Retterer caution that the matrix should only be used as an initial decision device, and the economic considerations involved in the warranty application must be considered.

A detailed analysis of the Dunn-Oltyan and Balaban-Retterer criteria disclosed that the Dunn-Oltyan factors were included in the Balaban-Retterer matrix. Therefore, it was determined that the Balaban-Retterer matrix was generally appropriate for this study. However, as this research was only concerned with the application of an

RIW-type warranty to organic depot workloads, the procurement factors of the Balaban-Retterer matrix were not appropriate. Thus, it was determined that the Balaban-Retterer matrix for only equipment and operational factors was an appropriate initial screening device for identifying potential candidates for organic depot warranties. This condensed matrix is presented at Appendix B.

Means of evaluation. Each aircraft inertial navigation system repaired at AGMC was tested against the Balaban-Retterer criteria matrix for equipment and operational factors. Data were available from system engineers and managers at AGMC to provide valid answers to the criteria matrix. Data were gathered from interviews with these managers and engineers. For those matrix questions which refer to provisions relative to a contractor, AGMC was considered as the contractor unless the provision related strictly to a procurement consideration in which case the criterion was considered inappropriate and not included in the matrix.

Additionally, the operational factor decision questions relative to reliability were addressed only for selected inertial navigation units because of the time constraint imposed for data collection and analysis. This analysis was conducted under procedures established by the reliability assessment portion (Research Question 2) of this proposal.

After the criteria matrix was applied to the AGMC repaired inertial navigation systems, two systems were selected for additional analysis. These systems were selected from those meeting the matrix criteria. If one system did not meet all the criteria, a system would have been selected which met the largest number of criteria with the invalid criteria being considered as limiting factors.

Research Question 2

> Do inertial navigation units fail in conformance with recognized reliability probability distributions? If so, could these distributions be used as the basis for building a warranty application methodology?

Background. Before developing reliability assessment procedures which will be used in building a warranty concept, it is necessary to provide the proper setting by discussing the relationships of failure to reliability and availability. Reliability was defined in Chapter I as "the probability that a device will operate adequately for a given period of time in its intended application [1:1]." In this definition, the term "probability" provides the basis for characterizing reliability as a quantitative measure by indicating the likelihood of success in the operation of the device. The primary variable in this research effort, time between overhaul (TBO), measures the actual hours a system is successful (operates) before a failure occurs. TBO is therefore a quantitative measure

which can be used to compute a system's reliability in terms of its probability of success. Because success stops when there is a failure, it is essential that the types of possible failures which occur during a system's operating life be defined. The three classes of failures are infant mortalities, random failures, and wearout (1:8). Together, these classes of failure form a continuous distribution which is frequently referred to as the "bathtub curve"— because of the decreasing-flat bottom-increasing shape. During the early life of a system, infant mortality results "from design, manufacturing, or inspection deficiency [1:8]." The frequency of infant mortality decreases as the system matures until it levels off and a more constant rate of random failure occurs. As the system enters the wearout phase, failure occurs at an increasing frequency until the system becomes non-operational. In the context of this research effort, failure was also defined in terms of where certain kinds of failures were repaired. Specifically, failures which could have been fixed at field level were not considered depot chargeable failures in developing a depot warranty methodology.

Reliability assessment. The procedures used in developing the reliability assessment portion of this research effort followed a certain sequence of events and used statistical methods. The sequence of events were: collection of

initial data, taking random samples, fitting the data samples to a family of reliability distribution curves, establishing specific distribution parameters which best fit the reliability data, and developing reliability forecasting techniques for use in warranty application. Each of these events is discussed in more detail in the remainder of this section.

Data were collected from a population of specific inertial navigation systems which satisfied the criteria addressed in Research Question 1. Data depicting the variable TBO were obtained by recording the operating time before failure for systems repaired during a certain time period. Once a random sample of 100 units had been taken, the data were fitted to a reliability probability distribution which best represented the actual distribution of the population variable TBO.

When faced with the problem of determining the underlying distribution of the data, there can be a tendency to assume the data fits a certain family of distributions because similar data has in the past (10:1). This assumption is dangerous because the data may fit another type of distribution better, and the researcher may limit the validity of his findings. Therefore, the researcher is obligated to show statistically that the derived underlying distribution of the variable is significantly probable (10:1). In order to solve this

problem, this research effort used a FORTRAN IV computer program called SIMFIT to test sample data and to determine the distribution which fit the data. SIMFIT has the capability to allow the researcher to test eleven basic distributions with an infinite variation in distribution parameters.

The four major families of distribution which apply to a very large portion of the parametric applications of reliability are binomial, normal, exponential/poisson, and Weibull distributions (16:4-5).

> The choice of a family of distributions for reliability analysis is based upon a combination of experience and convenience factors. For example, the key to proper usage of both the binomial and exponential distributions is the assumption that there is a constant intensity or rate at which failures occur. Thus, if it were known that in some time-to-failure data the failure rate were changing rather than constant, one would tend to look upon the Weibull family as a candidate group in preference to the exponential. Frequently, the selection of a family can be aided substantially by using graphical techniques or a statistical test [16:4-5].

The final results of SIMFIT also provided confidence levels "to indicate the probable range in which the probability distribution will fall [10:2]." These confidence levels were essential in assigning risk levels to reliability probabilities used for warranty application.

Warranty application methodology was based on the quality of fit achieved between a reliability probability distribution and the sample data. If a high level (90 percent confidence) of statistical certainty was attributed to

the fit, the resultant probability distribution was used to forecast the reliability of two of the inertial navigation systems. The ability to forecast reliability levels at various confidence levels is paramount to the development of a warranty concept in that it will indicate when systems should fail.

Research Question 3

> Do Depot Maintenance Service, Air Force Industrial Fund procedures provide sufficient flexibility to accommodate warranty cost considerations and visibility?

Background. To better understand the costing policy of the Depot Maintenance Service, Air Force Industrial Fund (DMS, AFIF), a brief description of the costing philosophy is necessary. The DMS, AFIF is one of several revolving fund accounts used by the Department of Defense to account for costs incurred by governmental activities in providing merchandise or services to other governmental agencies. Generally speaking, revolving funds, or working capital funds as they are also known, continuously sell merchandise or services to government customers and reinvest the proceeds from these sales back into the revolving fund for future operations. The objective of the revolving fund concept is to put the operation on a businesslike basis with the sales price for a particular good or service being designed to pay only the expenses of the operation and replenish the inventory. Therefore, in theory, revolving

funds cannot make a profit or incur a loss. The Air Force uses two revolving funds, a stock fund and an industrial fund, each of which has several divisions. The DMS, AFIF is one division of the revolving industrial fund (24:61).

The selling price of the good or service provided by an industrial fund is determined by summing the expected total cost of providing the product and dividing the sum by the expected activity. Selling prices are usually expressed in fixed unit prices for merchandise or rates per hour for services. The DMS, AFIF generally uses a fixed unit price for systems repaired (28). Table 1 details the fiscal year 1977 unit prices for the inertial navigation systems repaired at AGMC.

Actual repair costs for each unit repaired are accumulated in a cost accounting system to determine how well the unit selling price reflects the actual costs incurred. Although this comparison results in a profit or loss on the repair of an individual item, the selling price, in theory, should provide an overall balancing of costs when all units are completed.

An integral part of the revolving fund concept is the creation of a customer-client relationship between the fund and the entity paying for the merchandise or service. The customer-client relationship for the DMS, AFIF is created between the repair activity and the system's item manager who pays for all repair actions from an operation

and maintenance appropriation. Thus, because of the revolving fund breakeven constraint, the item manager must pay the repair activity for all work performed even though the work was required because of previous inadequate service from the repair facility. This constraint prevents the actual occurrence of a profit or loss by the repair activity (28).

Since the funding procedures used by DMS, AFIF activities are restricted by the Department of Defense, the present funding policies were considered as given limitations to this research. However, it was assumed that supplemental procedures, which did not violate the basic premises of the DMS, AFIF, could be implemented to provide cost visibility for the application of an organic depot warranty.

Previous analyses of organic depot warranties have found that the funding restrictions imposed by the DMS, AFIF (or Navy Industrial Fund) were a limiting factor in developing a viable organic depot warranty policy (15:15). Larkin stated the basic problem in his analysis when he asked, "How can a nonprofit Department of Defense maintenance activity enter into a profit motivated maintenance contract . . . ? [15:1]" His proposal to mitigate this problem was to view the cost savings as the result of the warranty application as a potential source of funds for additional procurements or "seed money if you will [15:1]."

An additional approach to this problem was implemented at the Oklahoma City Air Logistics Center through the use of "paper" dollars to reflect profits or losses incurred on a simple warranty applied to engines repaired there (26).

Means of evaluation. Due to the conceptual nature of this question and recognizing that DMS, AFIF procedures are fixed at Department of Defense level, the best approach to determine an appropriate costing policy was to conduct unstructured interviews of DMS, AFIF management personnel at Headquarters, Air Force Logistics Command (AFLC/MAJ) and the Financial Management Branch of the Directorate of Maintenance at AGMC. These interviews were conducted with the following basic questions which were designed to stimulate additional discussions.

1. If an RIW-type warranty were applied to an organic depot workload, which of the following funding approaches would you consider most appropriate?

   a. "Paper" dollar profit or loss.
   b. Allow the depot to retain profits.
   c. Recognition of cost savings as part of the Resource Conservation Program or Value-Engineering Program.
   d. Not feasible.
   e. Another approach.

2. In your opinion, would a "paper" dollar profit or loss operation statement provide a meaningful management tool?

3. Based on the fact that an organic depot must repair each system returned (up to the economic repair limit), does a warranty concept really have a place in the organic depot environment?

Based on the responses to these interviews, it was determined if warranty cost data could be developed within the present DMS, AFIF funding structure. If appropriate funding considerations for the application of an organic depot warranty were not evident, the potential impact of the warranty would be severely limited.

Research Question 4

> Would the development of an organic depot warranty methodology enhance the potential for decreased operation and support costs and increased reliability?

Background. Balaban and Retterer concluded that "the life cycle cost characteristic is a convenient and meaningful summarizing statistic for combining reliability, maintainability, and support cost factors [2:7-10]." Therefore, to properly evaluate the net effect of the application of an RIW-type warranty to an organic depot repair workload, a simulation of potential depot repair costs using various reliability assessments is appropriate.

To assess the effect of the application of an organic depot warranty, two techniques were used. The first technique simulated the application of an organic warranty to the inertial navigation system selected for reliability analysis in this research. The second technique used the AGMC Life Cycle Cost Model (20) to estimate annual organic depot repair costs for varying time between overhauls to demonstrate the potential for reduced operation and support costs.

Application of a
mock organic depot warranty. The inertial navigation systems selected as meeting the RIW criteria were used for the mock application. This application consisted of develing warranty provisions as to the parameters of a depot chargeable failure and a minimum operational time between overhaul for each unit based on an expected failure distribution. The parameters and time between overhaul requirement were based on the conditions in effect for the selected system at the time the mock warranty was applied. A sample of systems repaired during a given base period (1975-76) was tracked until the systems returned for depot repair at AGMC. After each unit was repaired, the type of repair required was analyzed in terms of the mock warranty provisions and time between overhaul requirements. If the system met the minimum time between overhaul requirement, AGMC received "full payment" for the item. AGMC also received full payment if the required repair action should have been accomplished at base level or if no repair was required even though the system did not meet the time between overhaul requirement. However, payment was not credited if the system did not meet the time between overhaul requirement, and a depot level repair was required. Data for this mock application were available at the Logistics Workload Branch of the AGMC Directorate of Maintenance and the Reliability Branch of the AGMC Inertial Engineering Division. Data were collected from the Work In

Process Removal Report (PCN 338411) and analyzed by the researchers.

An assumption in this mock application was that the distribution of failures would not be initially affected by the organic depot warranty application.

Life cycle costs with improved reliability. While various life cycle cost models are available to project costs, the AGMC Life Cycle Cost (LCC) Model developed by Richard W. Rogge of AGMC/XRX was considered the most appropriate for an evaluation of annual organic depot repair costs.

> The purpose of this LCC model is to provide the researcher, program manager, or any other interested party, with a model he may use to compare the . . . maintenance options on the same system [20:2].

The model also has a desirable feature in that certain variables not appropriate to the analysis may be eliminated. "For example, RDT&E may not be appropriate when comparing . . . annual logistics [costs], where the RDT&E has already been accomplished . . . [20:3]."

The AGMC LCC Model uses the following assumptions which must be considered when analyzing the results of the model. These assumptions are as follows:

1. Equal activity at all bases employing the system under study.
2. Any number of field repair locations but only one depot repair location.
3. Calculations of support equipment assume a machine hour/manhour relationship of 1:1.
4. No modifications will occur during the life of the system that will affect cost, reliability, or maintainability [20:4].

The AGMC LCC Model has been programmed in FORTRAN IV and can be used on a time sharing system (such as CREATE) or as a batch job on the IBM 360/50.

Input parameters for the AGMC LCC Model are in four categories: (1) applications; (2) constants; (3) system variables; and (4) line replaceable unit (LRU) variables.

The application variables consist of variables pertaining to the application of the inertial navigation system being costed and are entered as fixed current year values. The constant parameters pertain to field and depot maintenance activities and are also fixed in current year dollars. The system variables refer to the particular inertial navigation system under study and the LRU variables consist of parameters that vary with each system (20:5).

The output parameters of the model are summary costs, cost elements, and LRU cost outputs. The summary costs include acquisition costs, initial depot and field costs, recurring annual depot and field costs, and total life cycle costs. The cost element matrix summarizes annual base lvel costs and item management costs, while the LRU cost matrix specifies depot repair costs to the particular inertial system under review (20:5). This model has been analyzed and validated by the Air Force Acquisition Logistics Division XRSA Office.

Model application. The AGMC LCC Model was used in this research to develop annual depot repair costs for varying levels of reliability as determined in the reliability assessment portion of this study. Parameters in the model relative to acquisition costs were not considered (zero value), and cost parameters relative to depot level repairs were held constant in current year (fiscal year 1977) values. The variable input used to exercise the model was the TBO for the specific system under review. This variable was entered as part of the LRU variable matrix as variable MTBF (mean time between failure). Since TBO and MTBF were not computed in the same manner, the MTBF was estimated from the observed relationship of previous TBOs to MTBFs for the same system as calculated from the AGMC Reliability Engineering Failure Trend Report.

The resulting output from the AGMC LCC Model was an estimated annual depot level repair cost for various levels of reliability (TBO) for selected inertial navigation systems. From this data, it was possible to assess the economic aspects of a potential warranty application.

CHAPTER III

WARRANTY APPLICATION CRITERIA

INTRODUCTION

The potential benefits from the application of a warranty can only be achieved if the equipment is amenable to the use of the warranty. Therefore, before a decision is made to use a warranty, the equipment should be screened against established criteria to determine if the equipment's operational and design characteristics are suitable. Balaban and Retterer have established a warranty application criteria matrix for evaluating potential procurement actions for Reliability Improvement Warranty (RIW) applications as discussed in Chapter II. It is the purpose of this chapter to screen the eight aircraft inertial navigation systems repaired at the Aerospace Guidance and Metrology Center (AGMC) against the Balaban-Retterer matrix for equipment and operational factors. These criteria are presented in Appendix B.

EVALUATION

Although not specifically included in the Balaban-Retterer criteria, there are two overriding issues indicated in the Hughes Aircraft conclusion (Chapter I) which

must be met before consideration is given to the application of a warranty. These issues are that the unit should be of high dollar value and have a low mean time between failure. As indicated in Table 1, the unit cost of each aircraft inertial navigation system varies from $36,000 (LN-12) to $331,000 (N-16). When these unit costs are multiplied by the number of units in service, it is readily apparent that these units have a high dollar value in terms of acquisition cost ($373 million). Additionally, the fiscal year 1977 depot repair costs for these systems are estimated to be $16.8 million which also represents a significant dollar investment.

The second concern indicated by the Hughes researchers was that the units should have a low mean time between failure [MTBF or, for purposes of this study, time between overhaul (TBO)]. A further concern in this area is the number of units returning to the depot wit[illegible]ro or short duration operational hours. Table 2 presents a summary of TBO and returned unit hours for inertial navigation systems received at AGMC during 1976. The zero and short time intervals presented in Table 2 were designated by the item managers and represent the number of units received at AGMC from field units. The TBO figure represents the last quarterly average TBO for units returned to AGMC. As these systems were designed to have significantly higher TBOs (the KT-73 was designed to have a 650 hour TBO) (23), it is apparent that the systems have

Table 2

SUMMARY OF AIRCRAFT INERTIAL NAVIGATION SYSTEMS RETURNED TO AGMC, 1976

System	Total Received	Zero (a) Timers	%	Short (b) Timers	%	Others	%	TBO (Hours)
N-16	266	22	8.3%	31	11.7%	213	80.0%	357
LN-12	2,122	322	15.2%	186	8.8%	1,614	76.0%	362
LN-14	287	38	13.2%	72	25.1%	177	61.7%	198
LN-15	178	46	25.8%	37	20.8%	95	53.4%	193
KT-73	374	65	17.4%	50	13.4%	259	69.2%	299
FLIP	169	22	13.0%	23	13.6%	124	73.4%	213

Notes:

a. Zero time units are defined as units with less than 15 operational hours for all systems except the LN-14 which may accrue up to 20 hours. Hours are operational times based on ETI readings.

b. Short time units are defined as units with more than 15 but less than 50 operational hours for all systems except the LN-14 which ranges from 21 to 70 hours.

Source: AGMC Aircraft Statistical Failure Trend Report, 28 February 1977

relatively low TBOs. Additionally, the proportion of units failing after only a few operating hours is high, especially for the LN-14, LN-15, and the KT-73. Therefore, it was concluded that the aircraft inertial navigation systems repaired at AGMC are high investment assets and have low MTBFs.

Seventeen factors appropriate to assets already in use were selected from the Balaban-Retterer matrix. Ten of these factors were based on equipment factors, and seven factors were established for operational considerations. Interviews were conducted with AGMC Inertial Engineering and Maintenance personnel to develop the following conclusions.

Equipment Factors

Equipment maturity at an appropriate level. The AGMC engineers considered six of the aircraft inertial navigation systems to be operationally mature. This response was consistent with the fact that most of the supported weapon systems (F-4, A-7, F-111) have been operational for a number of years and the inertial systems have been repaired at AGMC for most of that time period. The excluded systems were the C-5A FLIP (floated lightweight inertial platform) and the B-52 LN-15. The FLIP was not considered to be operationally mature because:

> Even though the system has been in operational use for seven years, significant changes are . . . being made

> in the operational environment [relocation within the aircraft], hardware and software design, and operational deployments [23].

The LN-15 was excluded because of its recent application to the B-52 weapon system and sufficient time has not transpired to evaluate failure trends. It should be noted, however, that the excluded systems are not experimental in nature, but that the systems were exempted because adequate experience with the system in its current operational environment has not been achieved.

Control of unauthorized maintenance can be exercised and the units are field testable. The second and third equipment criterion were combined because of the direct interrelationship between the actions taken at field (operating base) level and the overall maintenance of the unit. The AGMC engineers were asked to identify what maintenance actions were performed at field level and what sub-assemblies could be removed and replaced within the unit. If the field level maintenance actions require considerable access into the sealed portion of the unit, it may not be possible to hold the depot responsible for internal failures.

The N-16 inertial reference unit is tested and calibrated at field level. Additionally, two gyros, three accelerometers, and over thirty electronic module boards internal to the unit can also be replaced at field level. As these replacement actions require access to the central

portion of the unit, the N-16 cannot be considered a sealed unit, and therefore, it would be difficult to properly assess failure modes to the repairing depot.

The LN-12 stabilized platform can also be adjusted at field level, and the two gyros can be removed and replaced. As this removal action requires entry into the unit, the LN-12 cannot be considered a sealed unit and may be subject to unauthorized maintenance actions at field level.

While the LN-14 is manufactured by the same firm as the LN-12 (Litton Industries), it does not utilize the field level gyro replacement policy. In fact, the field level maintenance policy for the LN-14 is limited to removing and replacing the entire unit; therefore, the LN-14 can be considered a sealed unit and not subject to unauthorized maintenance actions.

The LN-15 is similar to the LN-14 maintenance policy in that field level repair is not authorized. The inertial measurement unit is checked out before installation, and calibration of the gyros is performed using the aircraft's computer. Gyros and components are not replaced at field level. Thus, the LN-15 can also be considered a sealed unit and not subject to unauthorized maintenance.

The KT series of inertial measurement units represents a family of inertial instruments produced by Singer-Kearfott. The KT-71 and KT-73 units are similar in

design in that both units are tested and calibrated at the field level, and external electronic module boards can be removed and replaced in the field. However, these modules (three on the KT-71 and four on the KT-73) are located externally to the major cluster assembly containing the gyros, accelerometers and associated electronics. Therefore, the replacement of these modules does not require access to the unit, and the cluster assembly can be considered a sealed unit not subject to unauthorized actions. The KT-76 unit, while similar to the KT-71 and KT-73 in overall design, does not have replaceable modules and can also be considered a sealed unit.

The FLIP system is subject to the removal and replacement of eleven modular sub-assemblies as well as diagnostic and calibration testing at field level. Due to the removal of the sub-assemblies from the main unit, the C-5A FLIP cannot be considered a sealed unit; thus, unauthorized maintenance at field level is possible.

Unit can be properly marked or labeled to signify existence of warranty coverage. Each inertial navigation system could be labeled, and most units already have a label indicating that the unit was repaired by AGMC.

Unit is amenable to reliability and maintainability improvements and changes. The Inertial Engineering engineers stated that the operational reliability of every aircraft inertial navigation could be

improved, thereby establishing the probability that MTBF/TBO figures could be increased. While specific, technical proposals for increasing reliability were not solicited, the following areas received general support for improving reliability: redesign of certain assemblies of the system; better depot and field level test procedures; improved fault isolation at both depot and field levels; and increased awareness of the using commands to reduce the return of units not requiring a depot level repair.

Unit is reasonably self-contained. As discussed earlier, the system failure can only truly be identified to the unit if the unit is basically a sealed unit, and the failure of the unit is not caused by supporting or peripheral equipment. While some failures of the inertial unit may be attributable to other equipment (power supply, computer, etc.), the engineers generally agreed that the failures could be isolated to the unit for all systems. However, the possibility of a false failure due to unauthorized actions within the unit could lead to problems in isolating the failure to the unit. Therefore, a sealed unit becomes imperative for proper failure isolation.

Unit can be readily transported to the repair facility. As all systems are presently repaired at AGMC, it is apparent that the systems can be transported to the depot.

Unit has a high level of ruggedization. Most of the AGMC engineers surveyed were unsure as to whether failures were induced in the units during transportation to and from AGMC. Positive damage replies were received concerning the LN-12 and FLIP. Relative to the LN-12, the engineer stated, "Considerable damage is incurred by transportation. Many LN-12 shockmounts, gimbals, shafts, etc. have become distorted or have been replaced due to shock damage [23]." The C-5A FLIP assessment was "no visible damage, but definite degradation of performance characteristics [23]." As the other engineers did not positively attribute transportation problems as a failure cause, it can only be assumed that the other systems are not adversely affected to any large degree by transportation handling.

Unit maintenance is highly complex. The very nature of the inertial navigation systems dictates a highly complex repair process using specialized, computer test equipment, clean room conditions, and highly skilled repair technicians. The complexity of the process is further substantiated in that the Air Force Logistics Command has designated AGMC the technology repair center for inertial navigation systems. This designation signifies that AGMC possesses the technical skill capability to be the single point repair activity of inertial instruments for the Air Force. Based on this designation and the

nature of the repair process, the repair of all aircraft inertial navigation systems can be considered to be complex.

An elapsed time indicator can be installed on the equipment. All inertial systems except the KT-76 have elapsed time indicators (ETIs) installed on the unit.

Operational Factors

Use environment is known or predictable. Each system repaired at AGMC is used in a specific weapon system which performs basic Air Force operational missions. While these missions vary from weapon system to weapon system, the mission profiles for each weapon system are known and, in the opinion of AGMC engineers, the design of the inertial systems are consistent with the mission profiles.

Equipment operational reliability and maintainability are predictable. This criterion will be addressed in Chapter IV.

Equipment has a high operational utilization rate. While the inertial navigation system is not always required for mission accomplishment in all weapon systems (backup or alternate systems are available), it does play a major role by providing precise navigational data for use in all-weather and night operations and direct interface with weapons control systems. Thus, in assessing the total operational capability of the weapon system, the

inertial navigation system must be considered a key factor in overall mission accomplishment, and therefore, must have a high utilization rate. Additionally, because of the high unit acquisition price, only a limited number of spares were purchased; therefore, units do not remain on the storage shelf for excessive (over 30 days) time periods.

Warranty administration can be efficiently accomplished. To accomplish a warranty program efficiently, accurate data bases must be established to track the units through the depot to the field and record operational hours and failure modes. An additional requirement is that repair costs must be accurately recorded to permit the timely evaluation of the repair process.

At AGMC, three maintenance management data systems are already in existence, and with minor adjustments would provide timely, accurate data for warranty management. First of all, five of the aircraft inertial navigation systems (N-16, LN-12, LN-14, KT-73, FLIP) are classified as Serialized Control and Reporting Assets (SCARS). The SCARS system provides for Air Force-wide control and reporting of specific units by serial number and permits the item manager positive control over all units in the inventory. Secondly, as an adjunct to SCARS, AGMC has implemented the Repair and Evaluation Data Management Program for Aircraft Inertial Systems (G078C). This program was developed "to provide intensive diagnostic and analytical capability for

inertial reference units, inertial measurement units . . . [and] . . . stabilized platforms . . . [32:1-1]." The objectives of this program are to:

a. Reduce repair man-hours and material cost utilized during maintenance.
b. Reduce manual record keeping while improving the analytical and diagnostic capabilities to finitely isolate problem causes.
c. Collect pertinent data to support technical and engineering decisions concerning maintenance techniques, policy, and procedures.
d. Provide a feedback to using activities to improve test capability.
e. Utilize data from the field (T.O. 00-20-10-10, Historical Documents for Specific Inertial Navigation Systems) and TRC in constructing a chronological record of tests and repairs for examining the compatibility relationships of parts to assemblies, assemblies to weapon systems, and locations therein [32:1-1].

The key elements in this program are the tracking of each serially numbered inertial unit for all aircraft systems, the recording of ETI readings at shipment from the depot and at return to the depot (TBO), and the documentation of the type of repair afforded each unit. With this type of information available on each unit over an extended period, a sufficient data base is available to determine expected failure distributions and repair actions.

The third maintenance management data system available at AGMC which would directly interface with a warranty application is the Programming, Budgeting, and Costing (PBC) System used to accumulate repair costs for the Depot Maintenance Service, Air Force Industrial Fund. This system records repair costs for each serialized unit

as it is repaired at AGMC, and the costs are computed on an actual hour basis which gives greater accuracy. The AGMC PBC System also forms the basis for establishing the unit repair price as reflected in Table 1 and discussed in Chapter V.

Based on the existence of these data systems, it is apparent that sufficient records are already available to determine reliability assessments and permit failure analysis.

Unit reliability and usage levels are amenable to warranty application. As mentioned in the introduction and presented in Table 2, all aircraft inertial navigation systems have TBOs which are less than desirable. Therefore, all systems repaired by AGMC would be amenable to a reliability improvement.

Operating time exposure is known or predictable. Based on the information available in the G078C system, operating times for specific units are known and available. However, it is difficult to directly relate unit operational times (ETI hours) to aircraft flying hours because the inertial unit may not be required on every mission flown, and the unit can accrue operational hours on the ground during testing procedures. "This negates the use of flying hours for measuring mean time between failure [32:1-1]." The ETI readings available in G078C represent actual unit operational times between

failures, and this measure can be used for warranty applications. All systems are included in the AGMC Reliability Trend Report (based on G078C data) except the KT-76 which does not have an ETI, and the KT-71 which does not have a large workload (36 units in fiscal year 1977).

Provision has been made for computing the unit's mean time between failure. As stated in the previous paragraphs, the AGMC G078C system has the capability to compute MTBF/TBOs for all aircraft inertial navigation systems except the KT-76 which does not have an ETI.

CONCLUSIONS

The RIW application criteria established by Balaban and Retterer and validated by Dunn and Oltyan provide a meaningful basis for evaluating aircraft inertial navigation systems for a potential warranty application. Of particular importance are the control of unauthorized maintenance actions, the existence of an ETI meter, and the potential for reliability improvement.

Based on the circumstances previously stated, the N-16, LN-12, and C-5A FLIP cannot be considered as sealed units and therefore, the effect of unauthorized maintenance actions cannot be controlled. Thus, these systems should not be considered for a warranty application with their present configurations and field level maintenance policies.

It should be noted that while the KT-71 and KT-73 systems also have field replaceable external modules, the basic cluster assembly of both systems is a sealed unit and would be amenable to warranty coverage. As the LN-14, LN-15, and KT-76 are sealed units, they are best suited in this respect for a warranty application.

With the N-16, LN-12, and FLIP being eliminated, the remaining systems were evaluated as to the existence of an ETI meter. Without an ETI meter, operating hours cannot be determined and reliability computations cannot be made. The KT-76 was the only system without an ETI meter and therefore, must be eliminated from further consideration.

As the remaining systems (LN-14, LN-15, KT-71, KT-73) all exhibited the potential for reliability growth and met all of the remaining criteria, any one of these systems has the potential for a warranty application. The KT-71, however, has a limited workload forecast for future years (36 units in fiscal year 1977 and 38 units in 1978 and 1979). Therefore, the KT-71 was arbitrarily eliminated from the remainder of the study because of the limited opportunities for dollar savings.

The LN-15 was also eliminated from the remainder of this study because of the limiting factor of not being a mature system in the operational environment. The remaining systems (LN-14 and KT-73), having met all the additional application criteria, were then selected for further

reliability analysis. Table 3 summarizes the criteria test for the eight aircraft inertial navigation systems repaired at AGMC. Criteria which were met are indicated by a plus sign (+) while criteria which were not met are shown with a minus sign (-). If the AGMC engineers could not provide a definitive response, the criterion was scored as uncertain (?).

While it was the intention of the researchers to select one system for the reliability assessment, a desire was expressed by AGMC personnel to explore both systems. Since this approach presented the opportunity to evaluate two slightly different systems (totally sealed unit versus sealed cluster with replaceable external modules, LN-14 and KT-73, respectively), it was decided to examine the reliability of both the LN-14 and KT-73. Chapter IV presents the reliability assessment of these systems based on units repaired in 1975 and 1976.

Table 3

SUMMARY OF APPLICATION CRITERIA TEST

N-16	LN-12	LN-14	LN-15	KT-71	KT-73	KT-76	FLIP	CRITERIA
								Equipment Factors
+	+	+	-	+	+	+	-	1. Mature Equipment
-	-	+	+	+	+	+	-	2. Control of Unauthorized Maintenance
+	+	+	+	+	+	+	+	3. Field Testable
+	+	+	+	+	+	+	+	4. Labeling
+	+	+	+	+	+	?	+	5. Reliability Can Be Improved
-	-	+	+	+	+	+	-	6. Unit Is Self-Contained
+	+	+	+	+	+	+	+	7. Transportable to Depot
+	-	+	+	+	+	+	-	8. Unit Has High Level of Ruggedization
+	+	+	+	+	+	+	+	9. Complex Unit Maintenance
+	+	+	+	+	+	-	+	10. ETI Meter
								Operational Factors
+	+	+	+	+	+	+	+	1. Use Environment Is Predictable
*	*	*	*	*	*	*	*	2. Reliability Is Predictable
+	+	+	+	+	+	+	+	3. High Utilization Rate
+	+	+	+	+	+	-	+	4. Efficient Warranty Application
+	+	+	+	+	+	?	+	5. Reliability Amenable to Warranty
+	+	+	+	?	+	-	+	6. Operating Time Known
+	+	+	+	+	+	-	+	7. MTBF/TBO Computed
14	13	16	15	15	16	10	12	Meets Criteria
2	3	0	1	0	0	4	4	Fails Criteria

+ Meets Criteria - Fails Criteria ? Uncertain * Addressed in Chapter IV

CHAPTER IV

RELIABILITY ANALYSIS
FOR WARRANTY APPLICATION

INTRODUCTION

The warranty application criteria were applied to the inertial navigation systems repaired at Aerospace Guidance and Metrology Center (AGMC) in Chapter III. As a result of this application, two systems, the LN-14 inertial navigation platform module and the KT-73 inertial measurement unit were best qualified for warranty consideration. This chapter will examine the reliability of these two systems and the relationship of their failure rates to a warranty application methodology. Each system is discussed in the context of the data base used, the sample selection, and the reliability analysis results. The final section of this chapter will discuss how these analyses apply in developing a warranty application methodology.

KT-73 RELIABILITY ANALYSIS

System Description

The KT-73 inertial measurement unit (IMU) is used on the Air Force's A-7D and the Navy's A-7E aircraft. The KT-73 IMUs repaired at AGMC for the Air Force and Navy are

identical. Since each IMU is serially controlled, Air Force IMUs are returned to Air Force activities, and Navy IMUs are returned only to Naval units. The KT-73 reliability analysis within this research addressed Air Force but not Navy units. The KT-73 is part of the AN/ASN-90 inertial measurement set which provides the pilot with precise navigational data for use in all weather operations and direct interface with the fire control system (21:53). The IMU is a serialized control asset and operational hours are recorded on an internal elapsed time indicator (ETI).

The KT-73 consists of a sealed unit containing the inertial platform, which can be repaired at AGMC, and four external module boards which can be replaced at field level. However, it is possible for AGMC to receive a unit for depot level repair when only an external repair is required or when a failure does not truly exist. These situations can occur because of the lack of personnel or spare parts at base level or anomalies in base level test equipment which indicate a depot level repair failure when it does not exist (21:59).

To evaluate the type of repairs performed, each KT-73 repaired at AGMC is categorized as to the degree of repair afforded. These repair categories (RCATs) are as follows (27:1-7):

I - Retest OK (RTOK) or calibration of the Z gyro restraint only. RTOK refers to an inertial system received

at AGMC for which no maintenance actions were necessary in order that it be declared serviceable.

II - Replacement of external cards AR6, AR7, AR8, and/or AR9 only. This category equates to Authorized Repair Unaccomplished at Base (ARUB) which refers to an inertial system received at AGMC for which the only maintenance actions required to declare it serviceable were those authorized to be performed in the field.

III - Repair or replacement of components external to the cluster. This action is authorized at depot level only.

IV - Repair or replacement of the cluster or its components. This action is authorized at depot level only.

Data Base

Shipment and return data for the Air Force KT-73 IMUs are initially entered in separate shipment and return log books within the actual AGMC repair activity. This data includes by serial number shipped or returned, data with ETI reading and the RCAT necessary to place the unit in serviceable condition upon its return. Based on a manual extrapolation from the shipment log books, the population for analysis was identified as 392 repaired Air Force IMUs that were shipped in calendar year 1975. The consistent relationship between the number of shipments and returns per month is depicted in Figure 1. This consistency remained when the shipments and returns were separated by repair

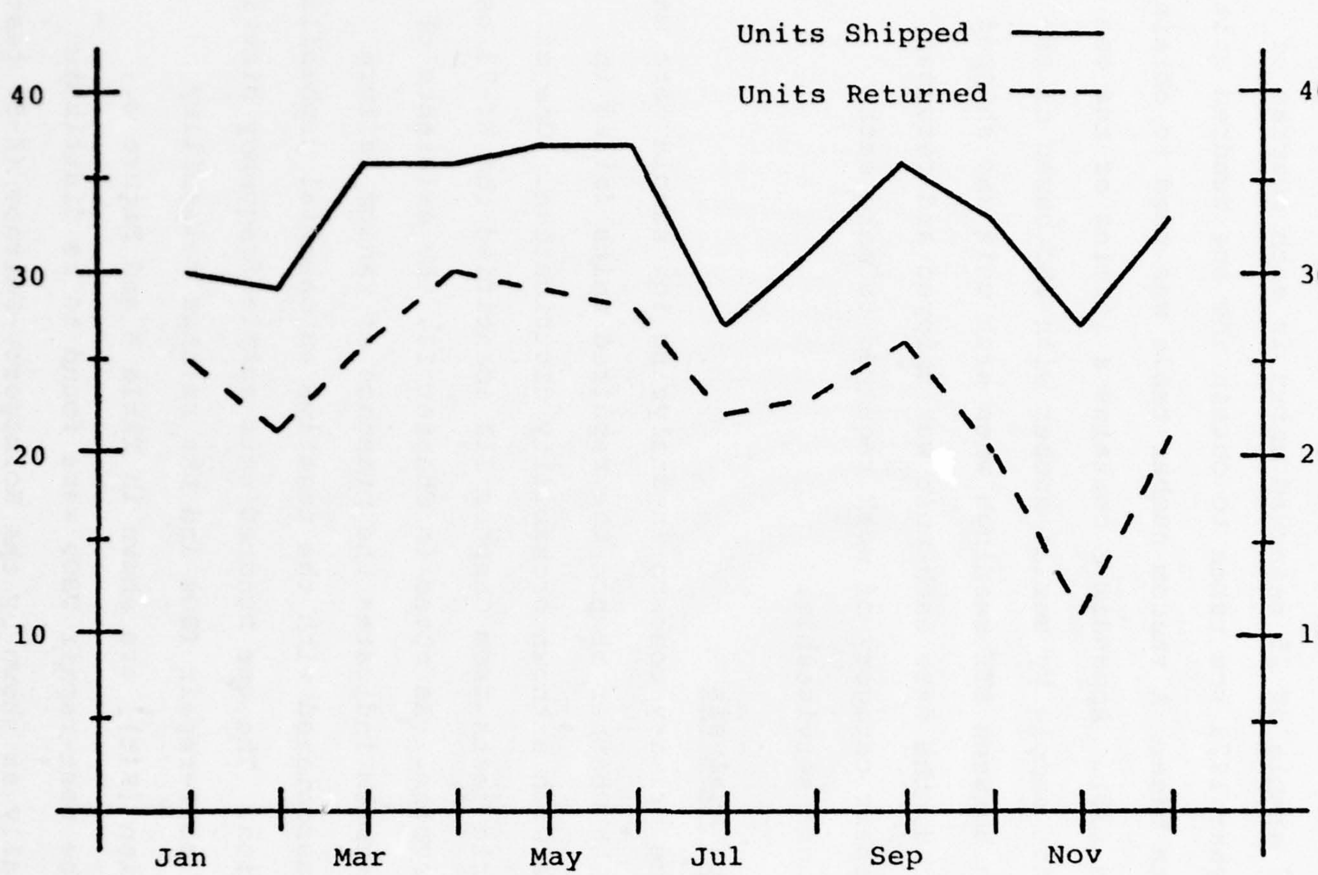


Figure 1

DISTRIBUTION OF KT-73 SHIPMENTS AND RETURNS, 1975

category as shown in Figure 2. As of May 1977, 285 of the 392 units had been returned to AGMC for repair. A random stratified sample of 25 returned units in each quarter of calendar year 1975 was taken to obtain the one hundred unit sample data base. A random number table was used to obtain the sample (33). Appendix C contains a listing of the one hundred unit sample by serial number with TBO based on the difference between ETI readings when each unit was shipped and returned, the date each unit was shipped and returned, and the repair category of work required to make each returned unit serviceable.

Sample Data Analysis

The primary concern in analyzing the sample data was to establish whether or not the repaired units failed in accordance with a known probability distribution. One of the criteria tests from Chapter III identified the KT-73 as a mature system. As noted in Chapter II, the existence of a mature system indicates the presence of random failure which is associated with the negative exponential probability distribution. The one hundred unit sample frequency distribution of post-repair TBOs and the related reliability distribution [R(t)] are shown in Table 4 and Figure 3.

The post-repair TBOs were found to be distributed exponentially as shown by the Kolmogorov-Smirnov (K-S) test in Table 5 (4:382).

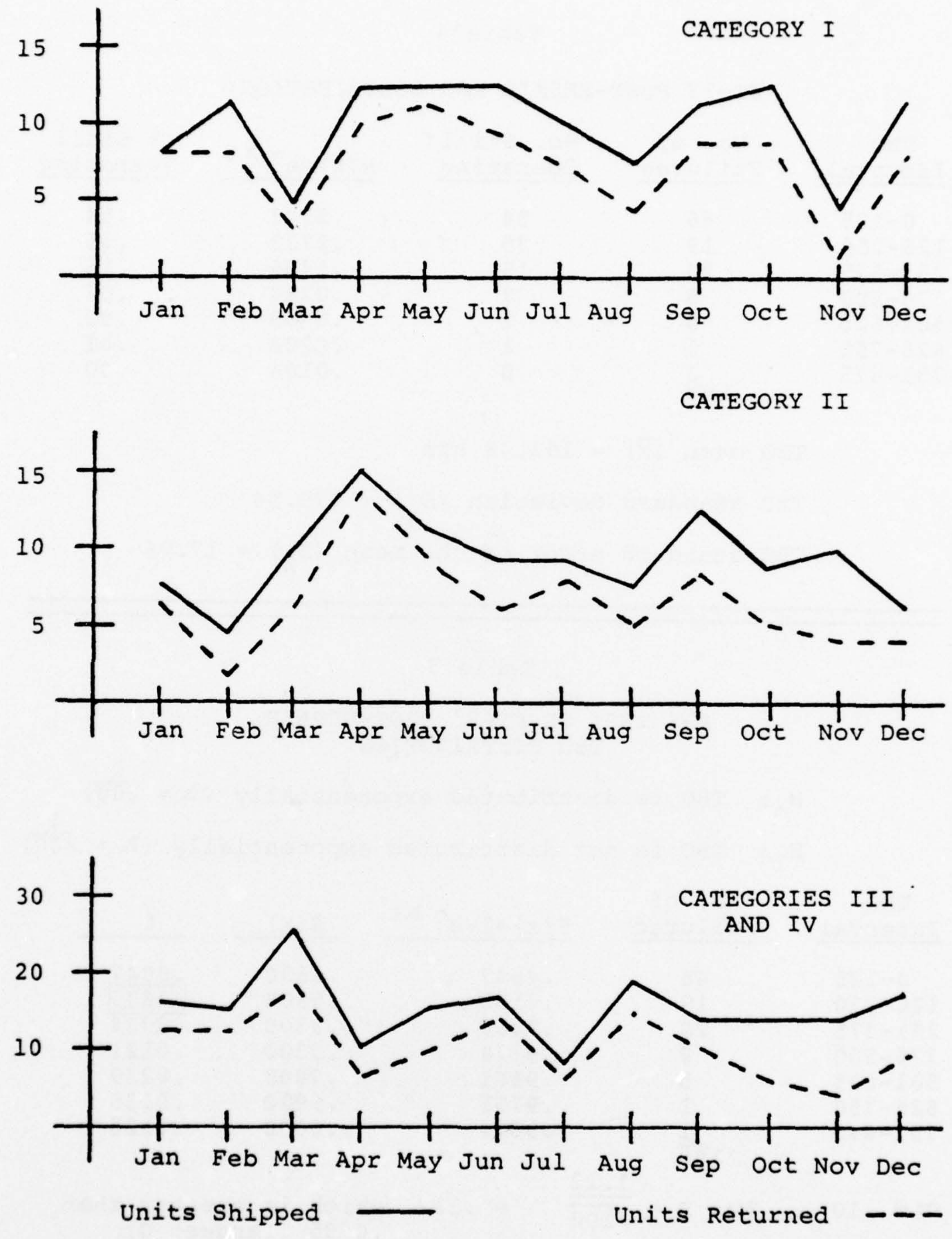


Figure 2

KT-73 SHIPMENTS AND RETURNS BY REPAIR CATEGORY, 1975

Table 4

KT-73 POST-REPAIR TBO DISTRIBUTION

TBO Interval	No. of Failures	No. Still Operating	$R(t)=e^{-\lambda t}$	% Still Operating
0-125	46	54	.5223	.54
126-250	19	35	.2728	.35
251-375	20	15	.1425	.15
376-500	8	7	.0744	.07
501-625	5	2	.0389	.02
626-750	1	1	.0203	.01
751-875	1	0	.0106	.00
	100			

TBO mean $(\bar{X})$ = 192.48 hrs

TBO standard deviation (S_x) = 179.54

TBO standard error of the mean $(S_{\bar{x}})$ = 17.96

Table 5

K-S TEST ON KT-73 POST-REPAIR
TBO DISTRIBUTION

H_o: TBO is distributed exponentially $(\lambda = \frac{1}{200})$

H_1: TBO is not distributed exponentially $(\lambda = \frac{1}{200})$

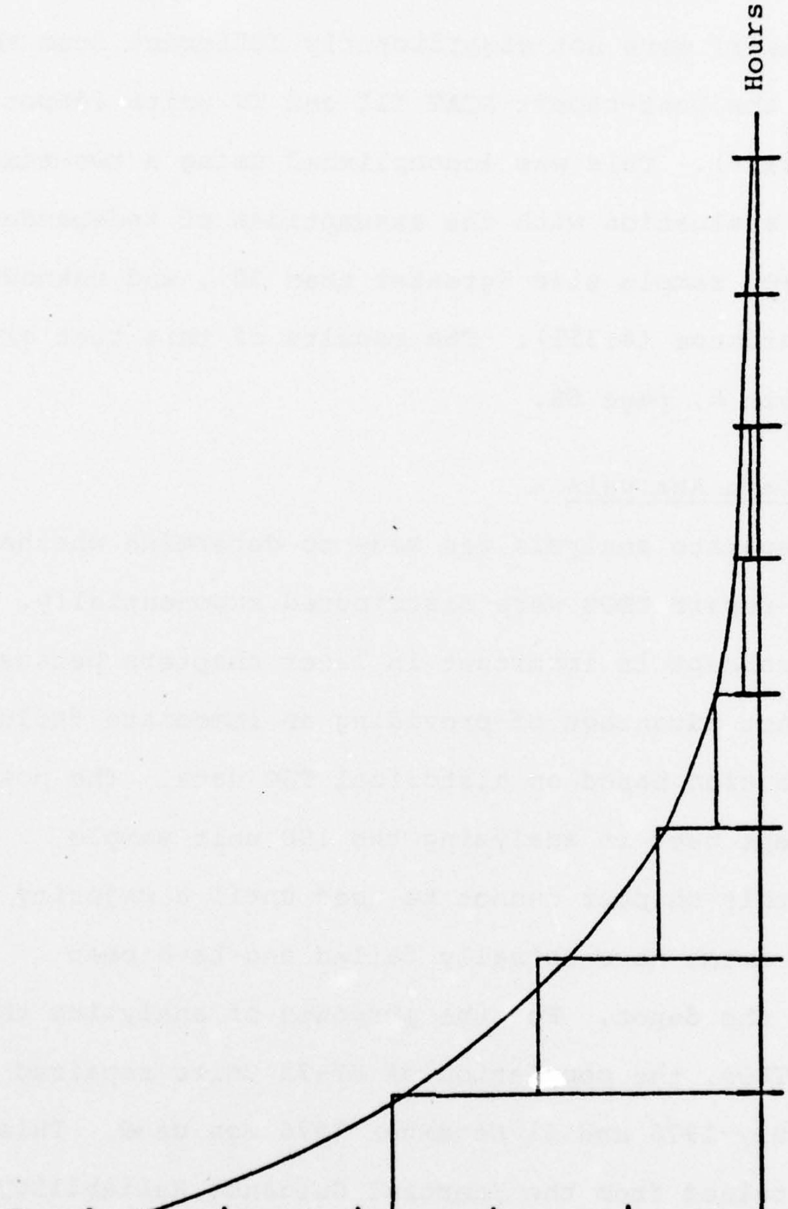
TBO Interval	No. of Failures	$F(x)=1-e^{-\lambda t}$	S(x)	D
0-125	46	.4647	.4600	.0047
126-250	19	.7135	.6500	$\boxed{.0635}$
251-375	20	.8466	.8500	.0034
376-500	8	.9179	.9300	.0121
501-625	5	.9561	.9800	.0239
626-750	1	.9765	.9900	.0135
751-875	1	.9874	1.0000	.0126
	100			

$\alpha = .10$ Max D $= \frac{1.22}{\sqrt{100}}$ = .122 which is greater than .0635 (largest D)

Therefore, H_o cannot be rejected, and it is concluded (with at least a 90% certainty) that the sample TBOs are distributed exponentially.

Figure 3

RELIABILITY DISTRIBUTION OF KT-73
POST-REPAIR SAMPLE UNITS, 1975



The next test undertaken determined that the mean TBO of the post-repair RCAT I and II units (non-depot required repair) were not significantly different from the mean TBO of the post-repair RCAT III and IV units (depot required repair). This was accomplished using a two-sample t-statistic evaluation with the assumptions of independent samples, large sample size (greater than 30), and unknown but equal variance (4:351). The results of this test are shown in Table 8, page 66.

Pre-repair Data Analysis

A separate analysis was made to determine whether or not the pre-repair TBOs were distributed exponentially. The pre-repair concept is important in later chapters because it has a distinct advantage of providing an immediate failure rate distribution based on historical TBO data. The post-repair concept used in analyzing the 100 unit sample earlier in this chapter cannot be used until a majority of the shipped items have actually failed and have been returned to the depot. For the purposes of analyzing the pre-repair TBOs, the population of KT-73 units repaired between 1 July 1976 and 31 December 1976 was used. This data was obtained from the Inertial Guidance Reliability and Configuration Program for Aircraft which is a data processing system designated as G078C. Input for the G078C is obtained from the same log books which provided

the data for the 100 unit sample which was previously analyzed. The resultant frequency distribution of pre-repair TBOs and the related reliability distribution [R(t)] are shown in Table 6 and Figure 4. The pre-repair TBOs were found to be distributed exponentially as shown by the Kolmogorow-Smirnov (K-S) test in Table 7 (4:382).

The results of a two-sample t-statistic evaluation showed that the pre-repair RCAT mean TBOs were not significantly different. These results are shown in Table 9.

LN-14 RELIABILITY ANALYSIS

System Description

The LN-14 inertial navigation platform module is used on the Air Force's F-111A/E aircraft. It performs the same basic function as the KT-73 but is a sealed unit without external module boards and cannot be repaired at base level. The LN-14 therefore has only two basic repair categories that are of interest from a warranty standpoint: retest OK (RTOK) and depot level repair.

Data Base

The LN-14 data base was acquired from the G078C data processing output which was discussed in connection with the KT-73 pre-repair data analysis. The population analysis was identified as 262 repaired LN-14 units that were shipped in calendar year 1975. As of May 1977, 185 of

Table 6

KT-73 PRE-REPAIR TBO DISTRIBUTION

TBO Interval	No. of Failures	No. Still Operating	$R(t)=e^{-\lambda t}$	% Still Operating
0-250	108	64	.3897	.37
251-500	33	31	.1519	.18
501-750	17	14	.0592	.08
751-1000	8	6	.0231	.03
1001-1250	3	3	.0090	.02
1251-1500	2	1	.0035	.01
1501-1750	0	1	.0014	.01
1751-2000	1	0	.0005	.00
	172			

TBO mean ($\bar{X}$) = 265.30 hrs
TBO standard deviation (Sx) = 325.60
TBO standard error of the mean ($S_{\bar{x}}$) = 24.83

Table 7

K-S TEST ON KT-73 PRE-REPAIR TBO DISTRIBUTION

H_0: TBO is distributed exponentially ($\lambda = \frac{1}{250}$)

H_1: TBO is not distributed exponentially ($\lambda = \frac{1}{250}$)

TBO Interval	No. of Failures	$F(x)=1-e^{-\lambda t}$	S(x)	D
0-250	108	.6321	.6279	.0042
251-500	33	.8647	.8198	$\boxed{.0449}$
501-750	17	.9502	.9186	.0316
751-1000	8	.9817	.9651	.0166
1000-1250	3	.9933	.9826	.0107
1251-1500	2	.9975	.9942	.0033
1501-1750	0	.9991	.9942	.0049
1751-2000	1	.9997	1.0000	.0003
	172			

$\alpha = .10$ Max D = $\frac{1.22}{\sqrt{172}}$ = .093 which is greater than .0449 (largest D)

Therefore, H_0 cannot be rejected and it is concluded (with at least a 90% certainty) that the TBOs are distributed exponentially.

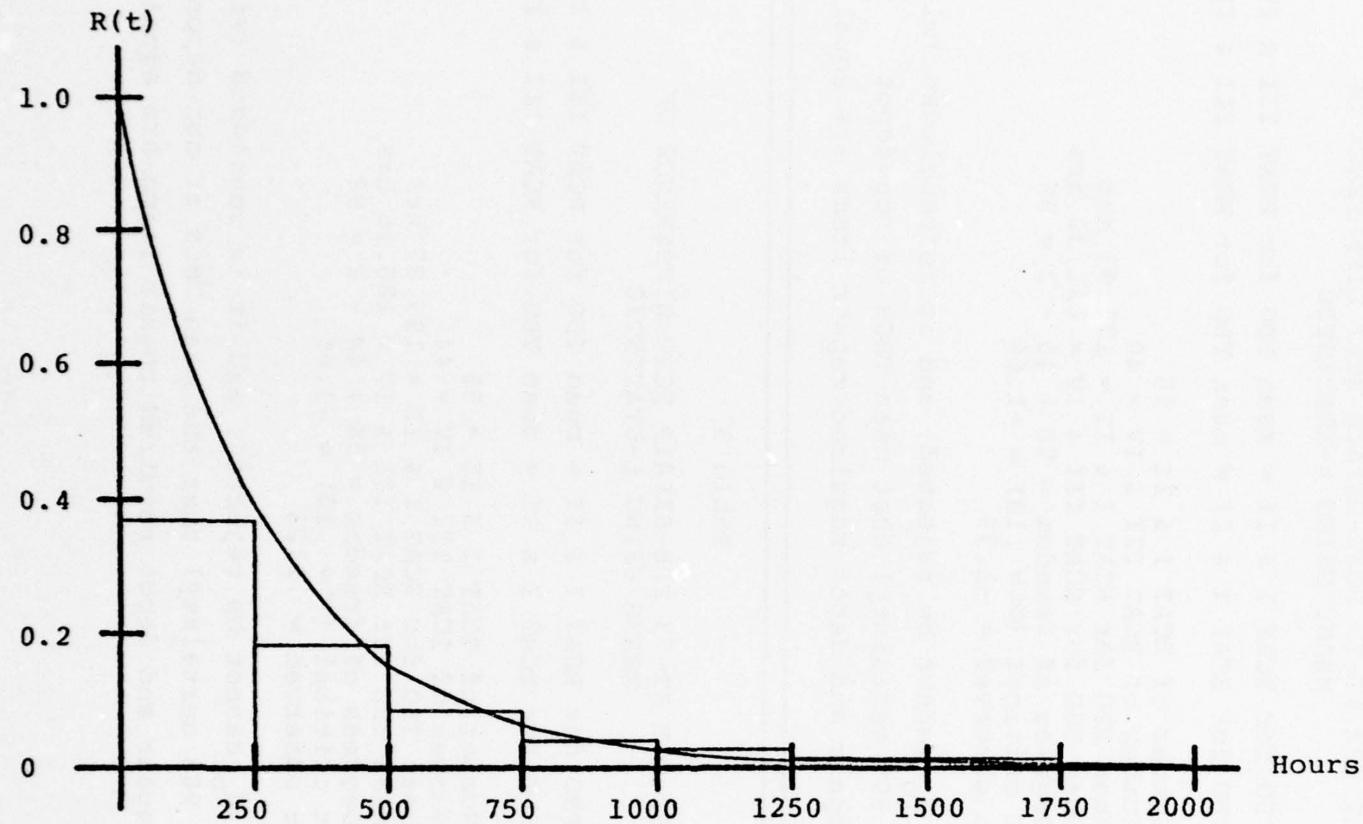


Figure 4

RELIABILITY DISTRIBUTION OF PRE-REPAIR
KT-73 UNITS SHIPPED BETWEEN 1 JUL 1976
AND 31 DEC 1976

Table 8

TEST FOR KT-73 POST-REPAIR RCAT DIFFERENCE OF MEANS USING t-STATISTIC

H_o: Mean TBO for RCAT I & II = mean TBO for RCAT III & IV

H_1: Mean TBO for RCAT I & II $\neq$ mean TBO for RCAT III & IV

Number of RCAT I & II = 58
Number of RCAT III & IV = 40
Mean TBO for RCAT I & II = 171.93 hrs
Mean TBO for RCAT III & IV = 221.32 hrs
Degrees of freedom = 58 + 40 - 2 = 96
t critical (α = .10) = -1.66
t observed = -1.33

Therefore, H_o cannot be rejected, and it is concluded (with at least a 90% certainty) that mean TBOs of non-depot required repair and depot required repair items are equal.

Table 9

TEST FOR KT-73 PRE-REPAIR RCAT DIFFERENCE OF MEANS USING t-STATISTIC

H_o: Mean TBO for RCAT I & II = mean TBO for RCAT III & IV

H_1: Mean TBO for RCAT I & II $\neq$ mean TBO for RCAT III & IV

Number of RCAT I & II = 56
Number of TCAT III & IV = 44
Mean TBO for RCAT I & II = 195.87 hrs
Mean TBO for RCAT III & IV = 188.16 hrs
Degrees of freedom = 56 + 44 - 2 = 98
t critical (α = .10) = -1.66
t observed = .2123

Therefore, H_o cannot be rejected, and it is concluded (with at least a 90% certainty) that the mean TBOs of non-depot required repair and depot required repair items are equal.

the 262 units had been returned to AGMC for repair. The consistent relationship between the number of shipments and returns per month is depicted in Figure 5. This consistency is also shown in Figure 6 which shows the shipments and returns by repair category. The same sampling procedure was used as was used with the KT-73. Appendix C contains the LN-14 100 unit sample data base.

Sample Data Analysis

As was found with the KT-73, the LN-14 is also considered a mature system with random failures which are associated with a negative exponential probability distribution. The 100 unit sample frequency distribution of post-repair TBOs and the related reliability distribution [R(t)] are shown in Table 10 and Figure 7.

The post-repair TBOs were found to be distributed exponentially as shown by the Kolmogorov-Smirnov (K-S) test in Table 11 (4:382).

A two sample t-statistic evaluation of the mean TBO of the two basic RCATs was conducted similarly to that on the KT-73. The sample had to be enlarged to the 185 failed units in order to have enough RTOK TBOs to satisfy the criteria of having a large sample size (greater than 30). The results of this test are shown in Table 12, page 72.

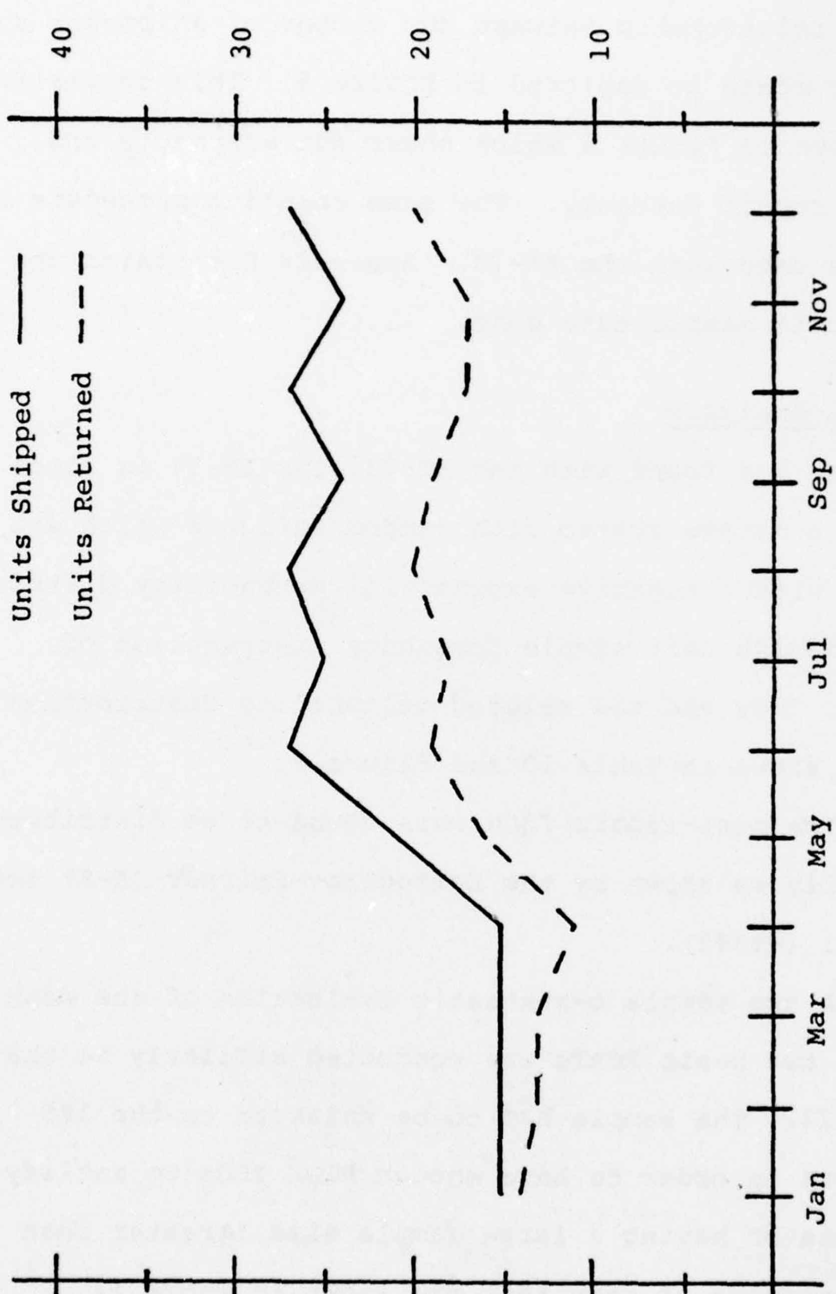


Figure 5

DISTRIBUTION OF LN-14 SHIPMENTS AND RETURNS, 1975

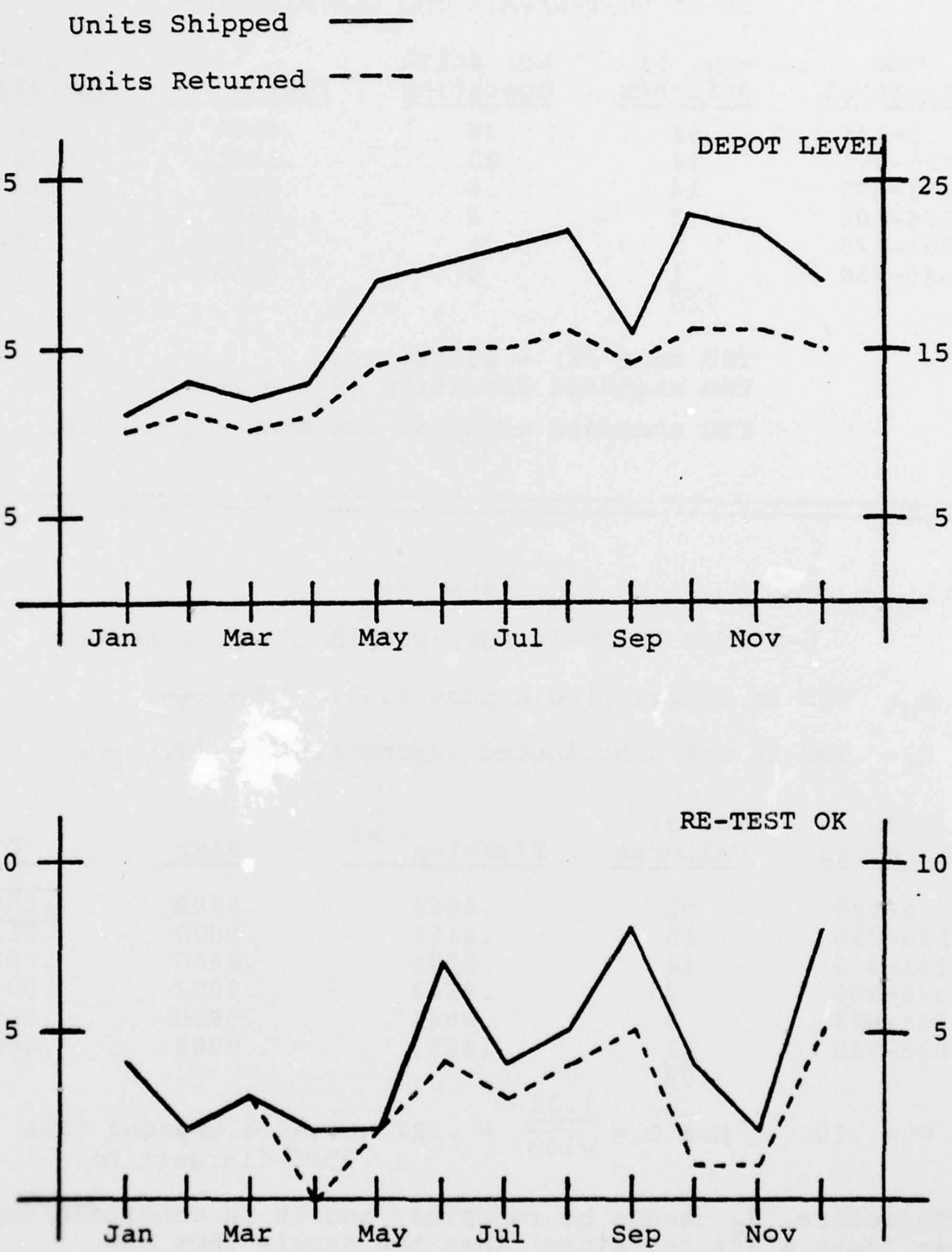


Figure 6

LN-14 SHIPMENTS AND RETURNS BY
REPAIR CATEGORY, 1975

Table 10

LN-14 POST-REPAIR TBO DISTRIBUTION

TBO Interval	No. of Failures	No. Still Operating	$R(t)=e^{-\lambda t}$	% Still Operating
0-125	62	38	.4038	.38
126-250	18	20	.1631	.20
251-375	14	6	.0658	.06
376-500	2	4	.0266	.04
501-625	3	1	.0107	.01
626-750	1	0	.0043	.00
	100			

TBO mean $(\overline{X})$ = 137.84 hrs
TBO standard deviation (S_x) = 140.01
TBO standard error of the mean $(S_{\overline{x}})$ = 14.01

Table 11

K-S TEST ON LN-14 POST-REPAIR TBO DISTRIBUTION

H_o: TBO is distributed exponentially $(\lambda = \frac{1}{150})$

H_1: TBO is not distributed exponentially $(\lambda = \frac{1}{150})$

TBO Interval	No. of Failures	$F(x)=1-e^{-\lambda t}$	S(x)	D
0-125	62	.5654	.6200	$\boxed{.0546}$
126-250	18	.8111	.8000	.0111
251-375	14	.9179	.9400	.0221
376-500	2	.9643	.9600	.0043
501-625	3	.9845	.9900	.0055
626-750	1	.9933	1.0000	.0067
	100			

$\alpha = .10$ Max D = $\frac{1.22}{\sqrt{100}}$ = .122 which is greater than .0546 (largest D)

Therefore, H_o cannot be rejected, and it is concluded (with at least a 90% certainty) that the sample TBOs are distributed exponentially.

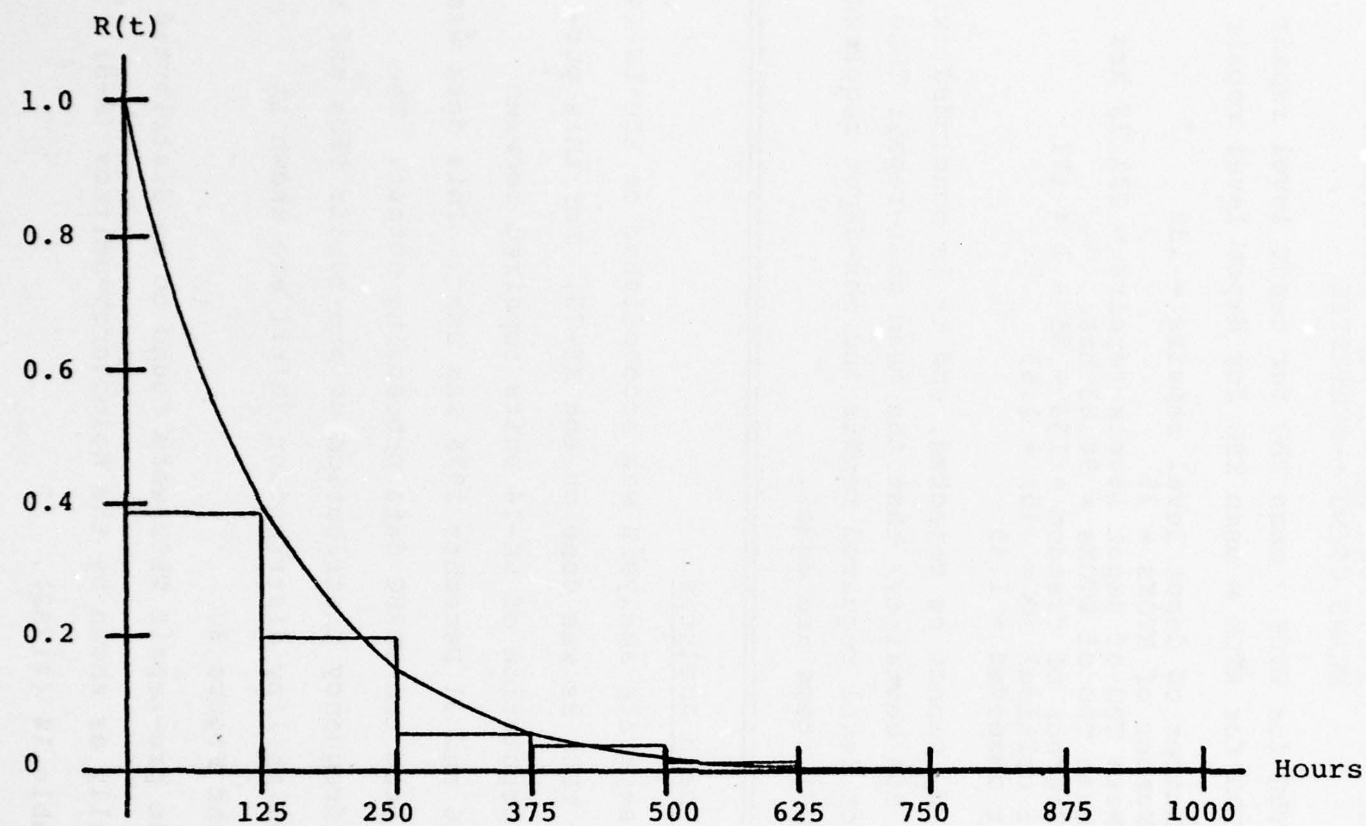


Figure 7

RELIABILITY DISTRIBUTION OF LN-14
POST-REPAIR SAMPLE UNITS

Table 12

TEST FOR LN-14 POST-REPAIR RCAT DIFFERENCE OF MEANS USING t-STATISTIC

H_o: Mean TBO for RTOK = mean TBO for depot level repair

H_1: Mean TBO for RTOK $\neq$ mean TBO for depot level repair

Number of depot level repairs = 138
Number of RTOKs = 35
Mean TBO of depot levels repairs = 131.78 hrs
Mean TBO of RTOKs = 98.83 hrs
Degrees of freedom = 138 + 35 - 2 = 171
t critical (α = .10) = 1.65
t observed = 1.45

Therefore, H_o cannot be rejected, and it is concluded (with at least a 90% certainty) that the mean post-repair TBOs of the depot level required repair and non-depot required repair (RTOK) items are equal.

Pre-repair Data Analysis

A separate analysis was accomplished on the LN-14 pre-repair TBOs as was done on the KT-73. For this purpose, the population of LN-14 units repaired between 1 July 1976 and 31 December 1976 was used. This data was extracted from the G078C data processing output. The resultant frequency distribution of pre-repair TBOs and the related reliability distribution [R(t)] are shown in Table 13 and Figure 8.

The pre-repair TBOs were found to be distributed exponentially as shown by the Kolmogorov-Smirnov (K-S) test in Table 14 (4:382).

Table 13

LN-14 PRE-REPAIR TBO DISTRIBUTION

TBO Interval	No. of Failures	No. Still Operating	$R(t)=e^{-\lambda t}$	% Still Operating
0-125	68	58	.4884	.4603
126-250	26	32	.2386	.2540
251-375	16	16	.1165	.1270
376-500	6	10	.0569	.0794
501-625	5	5	.0278	.0397
626-750	3	2	.0136	.0159
751-875	0	2	.0066	.0159
876-1000	1	1	.0032	.0079
1001-1125	1	0	.0016	.0000
	126			

TBO mean $(\overline{X})$ = 174.45 hrs

TBO standard deviation (S_x) = 198.53

TBO standard error of the mean $(S_{\overline{x}})$ = 17.69

Table 14

K-S TEST ON LN-14 PRE-REPAIR TBO DISTRIBUTION

H_o: TBO is distributed exponentially $(\lambda = \frac{1}{200})$

H_1: TBO is not distributed exponentially $(\lambda = \frac{1}{200})$

TBO Interval	No. of Failures	$F(x)=1-e^{-\lambda t}$	S(x)	D
0-125	68	.4647	.4603	.0044
126-250	26	.7135	.7143	.0008
251-375	16	.8466	.8413	.0053
376-500	6	.9179	.9207	.0028
501-625	5	.9561	.9604	.0043
626-750	3	.9765	.9763	.0002
751-825	0	.9838	.9763	$\boxed{.0075}$
826-1000	1	.9933	.9922	.0011
1001-1125	1	.9964	1.0000	.0036
	126			

$\alpha = .10$ Max D = $\frac{1.22}{126}$ = .1087 which is greater than .0075 (largest D)

Therefore, H_o cannot be rejected, and it is concluded (with at least a 90% certainty) that the sample TBOs are distributed exponentially.

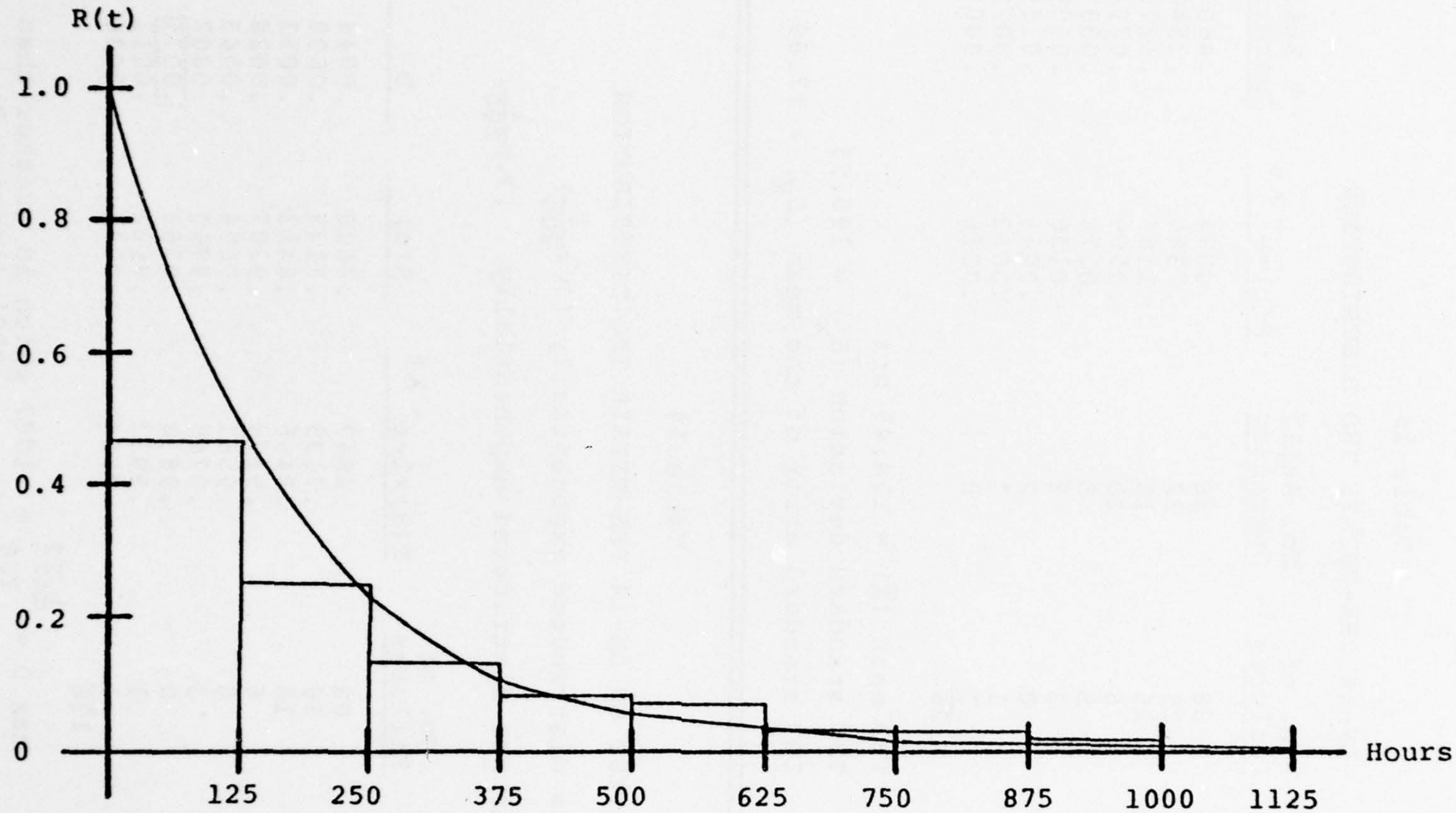


Figure 8

RELIABILITY DISTRIBUTION OF PRE-REPAIR
LN-14 UNITS SHIPPED BETWEEN 1 JUL 1976
AND 31 DEC 1976

WARRANTY IMPLICATIONS

The key element in applying a warranty is in knowing the risks involved with setting a warranty level. As in the case of the KT-73 and LN-14, how many failures could a manager expect at various possible TBO warranty levels? Since it has been shown that both systems fail exponentially, it therefore becomes relatively easy to predict the failure rate based on a predetermined TBO. Appendix E presents the type of matrix a manager could use in predicting the failure rate. The first step would be to estimate the system TBO either by using historical data and/or other forecasting techniques. Then the manager could read horizontally from the selected TBO and determine what percentage of his units would operate (survive) how long in terms of 100 hour intervals. For example, if a TBO were estimated to be 200 hours and a warranty level was set at 100 hours, then approximately 61% of the units would operate longer than 100 hours. In other terms, 39% of the units would fail before being operational 100 hours and would therefore require repair under the warranty. This concept is discussed further in a more detailed warranty example covered in Chapter VI.

CONCLUSION

The KT-73 and LN-14 exhibit random failure rates and have been shown to have exponentially distributed

operating hours. This conclusion applied to both pre-repair and post-repair operating hours where pre-repair was based on analyzing the TBOs of units before they were shipped, and post repair was based on tracking shipped units until they failed and were returned to the depot for repair. Additional tests (t-statistic) were made which verified that the mean operational hours by repair category did not differ significantly. All statistical tests were made at a statistical significance of at least ninety percent.

CHAPTER V

DEPOT MAINTENANCE SERVICE, AIR FORCE INDUSTRIAL FUND ORGANIC DEPOT WARRANTY IMPLICATIONS

INTRODUCTION

Balaban and Retterer indicate that the incentive power of a reliability improvement warranty (RIW) application to enhance or reduce the contractor's final profit is the key factor in making the RIW concept work.

> The contractor takes on an obligation for maintenance support for a specified period on a fixed-price basis . . . . Ideally, then, he [the contractor] will be motivated to increase reliability to reduce his costs [2:2-2].

Based on this statement, the Air Force Interim Guidelines for Reliability Improvement Warranty concluded that an RIW application should use a fixed price contract for a period of three to five years to allow reliability improvements to take effect (29:5).

While these basic provisions were established for RIW applications between the Government and contractors where profit is a direct consideration, the circumstances are different for an organic depot warranty application where provisions of the Depot Maintenance Service, Air Force Industrial Fund (DMS, AFIF) apply. It is the purpose of this chapter to present the costing and funding differences

inherent in the DMS, AFIF operation and to determine if DMS, AFIF provides sufficient flexibility to permit the application of an organic depot warranty.

DMS, AFIF POLICIES AND PROCEDURES

The DMS, AFIF is a working capital account used to finance the operating costs of depot-level maintenance at activities under the management control of the Air Force Logistics Command. Using an initial working capital base (the corpus) the DMS, AFIF operates as a revolving fund to allow the recovery of operating costs through the sale of products or services. The products or services are sold to buyers established through the issuance of a project order to create a contractual buyer-seller relationship.

> (1) The customer (buyer) budgets for work requirements and receives financial authority [operations and maintenance appropriations] for the work that may be ordered from the DMS, AFIF.
> (2) The DMS, AFIF (seller) prepares an operating budget stating the projected operating expenses and offsetting revenues. Working capital is provided to cover operations until payments are received from the customer.
> (3) The customer orders the work from the DMS, AFIF activity. This is accomplished through the use of funded project orders or annual customer orders.
> (4) The maintenance activity performs the work funded in the project order. As work is accomplished, resources are consumed and costs incurred. The DMS, AFIF pays for these expenses from its working capital. Periodic progress billings are processed to the customer to recover cash paid for the expenses incurred.
> (5) The payments from customers as the result of progress billings are used to replenish the DMS, AFIF working capital.

(6) As work is completed, the DMS, AFIF bills the customer in accordance with the terms of the project order. This is recorded as a sale and serves to liquidate the progress billing [25:1-2].

Figure 9 presents this process.

While the overall objective of the DMS, AFIF is to provide products and services on a breakeven basis, current policies permit the use of profit or loss factors to compensate for prior years' gains or losses. The use of these factors in the long term sense allows "greater stability of sales prices and avoidance of accumulated profits or losses from fiscal year to fiscal year [25:1-2]."

Each workload performed by a DMS, AFIF activity should earn sufficient revenue to satisfy operating expenses. To meet this objective, sales prices are constructed to offset all applicable costs expected to be incurred as an expense during the period for which the prices are applicable. The sales prices are developed for a fiscal year in conjunction with the development of the DMS, AFIF operating budget. Expenses included in the budget and the sales prices are civilian labor costs and benefits, expense of material consumed in the maintenance process, alterations of real property relative to the maintenance activity up to $75,000, tools and equipment having a unit value of less than $1,000, facility maintenance, equipment maintenance, and general and administrative costs to include custodial services, TDY, training, printing, utilities, and contractual services (25:1-5).

Source: AFLCR 66-9

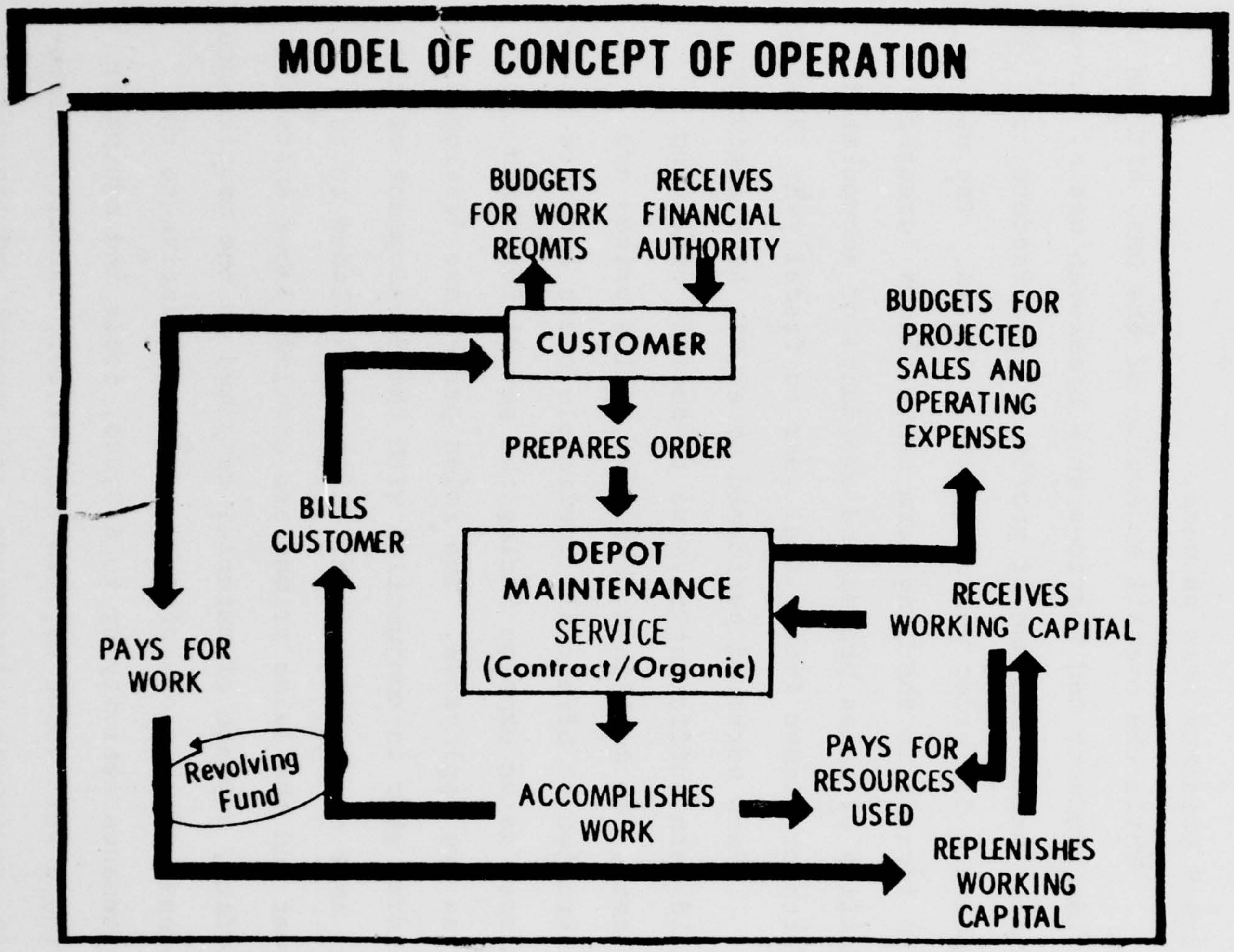


Figure 9

MODEL OF CONCEPT OF OPERATION

WARRANTY IMPLICATIONS

Based on discussions with AFLC and AGMC industrial funding personnel and in-depth reviews of governing regulations and directives, four key areas were found where the application of an organic depot warranty would have direct implications. These areas are discussed in the following paragraphs.

Profit and Loss Allowances in the DMS, AFIF

As noted in Chapter II, the overriding issue in using a warranty concept for a DMS, AFIF activity is how can a non-profit activity make a profit or incur a loss and thereby utilize the warranty concept. However, under the present unit pricing structure used by DMS, AFIF activities, profit and loss adjustments are used in developing unit sales prices. While these adjustments are currently used to compensate for prior year gains or losses, K. B. Mildon of AFLC/MAJ stated that it may be possible to use these adjustments to "incentivitize" an organic depot warranty application (18). If the profit/loss adjustment factor could be used in a warranty application, it could only be used, however, to measure cost savings or losses and could not be used to obtain additional funds (profits) for the depot. Additionally, the use of the profit/loss objective would require considerable managerial judgment as the

objective would have to be projected over future fiscal years to produce meaningful results, and prior year profits or losses due to workload or cost fluctuations would require separate considerations. Therefore, while the profit/loss factor does provide some flexibility in developing unit sales rates for a potential warranty application, the actual procedures required to implement such a process would be complicated and subjective. Also, procedural directives for the DMS, AFIF would require amendment to permit the use of the profit/loss objective in this manner. Table 15 presents the fiscal year 1977 AGMC sales price including profit and loss adjustments.

Annual Sales Rates Versus Multi-Year Fixed Price Contract

The use of the RIW concept in procurement actions is predicated on the use of a multi-year, firm fixed price contract to permit reliability growth and improvements over an extended period. Under current DMS, AFIF procedures, sales prices are computed and negotiated on an annual basis. The primary reasons for this approach are the need to match expenses of the current period with revenues and the annual fiscal year appropriation of operation and maintenance funds to the buyer. While an objective of the DMS, AFIF is to stabilize sales prices (as part of the DoD Rate Stabilization Program) (25), it may be difficult to provide stable prices with a warranty provision and still properly match

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Table 15

AGMC SALES PRICES,
FISCAL YEAR 1977

System	Direct Labor	Direct Material	Overhead	G & A	Profit/ Loss	Total
N-16	$2,387	$1,455	$2,024	$ 888	$-455	$6,299
LN-12	1,716	884	885	658	-274	3,869
LN-14	1,446	640	870	547	-280	3,223
LN-15	1,325	609	732	498	-208	2,956
KT-71	1,630	586	998	612	-313	3,513
KT-73	1,393	564	940	523	-218	3,202
KT-76	1,221	606	1,711	458	-191	3,806
FLIP	3,888	2,752	2,903	1,491	-293	10,741

Source: AGMC/MAWF

current revenues to current expenses. Thus, under current DMS, AFIF procedures, it is not possible to provide firm fixed prices over several fiscal periods. However, with the increased emphasis provided by the DoD Rate Stabilization Program, a de facto fixed price with warranty considerations included in the profit/loss adjustment may be possible (18). Additionally, the need to provide a fixed price over several fiscal periods may not be necessary if the warranty considerations are adequately handled in the profit/loss adjustment.

DMS, AFIF Cash Flows and Revenues

The DMS, AFIF operates under the concept of matching revenues to current expenses. Revenues are earned as the work (repaired unit) is completed; therefore, to provide sufficient cash to meet current expenses, progress payments are made by customers to the DMS, AFIF activity, and the progress payments are liquidated as units are completed (revenue). Using this concept, the DMS, AFIF receives credit for each unit repaired under the terms of the project order, regardless of how well the repaired unit performs. Additionally, the DMS, AFIF activity receives the full unit sales price for each unit repaired even though the unit does not require depot level repair (re-test OK [RTOK] or field level repair not accomplished). Thus, the unit sales price is a weighted repair cost based on an "average" unit repaired

during the fiscal year. The average unit price is determined based on the projected workload from the item manager as stated in the project order and the expected repair mix of units received during the period.

Identification of Costs Due to Defective Work or Spoilage

Costs incurred by a DMS, AFIF activity for direct depot maintenance work on a unit have traditionally been reported only as repair costs. Thus, it has been very difficult, if not impossible, to determine the costs of reworking an item because of defective work or spoilage. However, under new procedures established by the DoD Depot Maintenance and Maintenance Support Cost Accounting and Production Reporting Hankbook (DoD 7220.29-H), an indirect cost account for this purpose has been established. While the basic intent of this provision is to identify costs of rework due to quality control rejections, the Handbook also states that "defective work . . . costs include . . . the cost of redoing guaranteed work and the cost of reinspection of defective work . . . . [35:360-3]." With this cost account available, it will now be possible to accumulate costs to repair units not meeting guaranteed (or possibly, warranted) work. While this type of account is not required for a warranty application, it will provide an accounting of costs incurred due to warranty failures which would be of considerable management interest with a warranty application.

CONCLUSIONS

Although the DMS, AFIF basic philosophy is to operate on a breakeven basis, the overall funding concept does recognize the existence of profit and loss factors to adjust annual unit sales prices. While these profit or loss factors do not presently include definitive considerations for warranty applications, there is sufficient flexibility in the DMS, AFIF structure to permit their use as management measures of reliability improvements. However, due to the annual appropriation funding approach necessitated by the Federal budget, the use of a warranty funding approach is limited to application at the time of repair based on pre-repair operating hours and failure type. The post-repair warranty approach of monitoring units repaired in a given period until they fail, would not be feasible under DMS, AFIF procedures because of the multi-year funding considerations of projecting expected failures over several years.

An additional consideration in developing an organic depot warranty policy is the management incentive requirement which is the key element in a commercial RIW application. Because of the long range DMS, AFIF breakeven policy, the depot would not be permitted to retain profits from reliability improvements, but would be required to reduce future sales rates. Conversely, if the depot incurred losses because of poor reliability performance, the loss would be

recouped through increased sales rates in the next period. However, the use of a depot warranty would direct management attention to the problems of low operating hour units and RTOKs by associating costs with these units. Using this approach, it would then be possible to address the problems of improving reliability by reducing RTOKs and increasing operating hours by identifying the depot repair costs the Air Force incurred in repairing these assets.

CHAPTER VI

APPLICATION OF A POTENTIAL WARRANTY POLICY

INTRODUCTION

An integral part of the development of an organic depot warranty methodology is a demonstration of a possible warranty application to establish the feasibility and meaningfulness of the warranty. It is the purpose of this chapter to describe one possible approach to applying a warranty to organic depot workloads and to describe how management actions under a warranty application may be taken to reduce operations and support costs. The mock warranty was applied to a selected workload of both the KT-73 and LN-14 systems which were analyzed in Chapter IV after meeting the warranty application criteria in Chapter III.

MOCK WARRANTY APPLICATION

Background

Based on the findings and conclusions presented in Chapter IV, it was determined that the key components in developing a warranty expected failure distribution were the verification of the distribution, the parameters of the distribution, and the percentage of failed units not

requiring depot level repair (re-test OK or field level repair not accomplished). In developing a warranty application methodology, these components, along with a minimum warranted operational time, form the basis for the entire warranty program. While a complete warranty program must also include other considerations (detailed failure analysis, failures induced by unauthorized actions or improper use, and failures due to transportation damage), these areas are beyond the scope of this mock application. Additionally, to provide for the proper management incentive, a costing methodology must be developed to measure the results of the warranty program. The development of an expected failure distribution and possible costing methodology will be presented in the following paragraphs.

Expected Failure Distribution

As a result of the tests conducted in Chapter IV, the distribution of pre-repair and post-repair failures for both the KT-73 and LN-14 were determined to be exponentially distributed. If it can be assumed that future units will also fail in the same random manner, the exponential distribution can then be used to predict survival (or failure) probabilities based on specified population TBOs. Appendix E presents the expected failure percentages for various population TBOs for exponential distributions.

After the failure distribution has been specified, the parameters of the distribution must be identified to

permit the determination of the expected failures. In using the exponential distribution, the population TBO or failure rate must be specified (the failure rate is the reciprocal of the population TBO). While various statistical procedures (regression, time series analysis) are available to forecast future values, these techniques are beyond the scope of this research and were not evaluated; thus, the population TBOs for this mock application were arbitrarily selected. Even in an actual application, it will be necessary to consult with systems engineers, maintenance personnel, and item managers to develop a mutually acceptable TBO for the population and not rely strictly on statistical forecasting.

Since the units returning to the depot as failed items may not require a depot level repair, it is also necessary to specify an expected percentage of units which will not require depot level repair. This determination is required because units not needing a depot level repair would not be chargeable failures to the depot. It may be feasible to statistically predict these values from historical data available in the maintenance data systems; however, for purposes of this research, the percentages were arbitrarily selected.

The final element of the failure distribution portion of the warranty application is a function of a subjective determination after the failure distribution and

parameters have been determined. This element is the warranty cut-off figure or the amount of operational hours which will be warranted for each unit. As this decision must be subjectively made, it should include inputs from engineers, maintenance personnel, and item managers. The warranty cut-off decision must be made utilizing the expected failure distribution and RTOK rate. While the cut-off figure is subjectively determined, the use of the failure distribution with expected parameters will provide management with a basis for reducing the uncertainty in the decision process.

Costing Methodology

As noted in Chapter V, the Depot Maintenance Service, Air Force Industrial Fund (DMS, AFIF) procedures do provide some flexibility in developing a warranty policy based on pre-repair operating hours. This approach is possible because the depot receives credit for the unit at the time the repair is completed, and the sales rate earned could be adjusted for warranty considerations through the profit/loss factor. The following example illustrates a possible costing approach.

The basis for the proposed costing system, to be used in conjunction with the DMS, AFIF is the total workload (units) to be accomplished and the total DMS, AFIF costs to be recovered in accomplishing the workload. Using the total

repair cost, a warranty unit price could be established by dividing the total cost by the expected number of units exceeding the warranted TBO plus those units failing the TBO criteria but not requiring depot level repair.

For example, if the annual workload is 200 units with a DMS, AFIF unit sales price of $3,000 per unit, the total costs to be covered are $600,000. If the population TBO of 200 hours with a warranty cut-off of 100 hours is specified, 39 percent of the units (78 units) can be expected to fail within 100 hours or less. Given a RTOK rate of 50 percent, 39 units could be expected to fail with 100 hours or less and require depot level repair. Therefore, the depot could expect to receive 161 units not requiring depot repair. Using these units (161), the depot warranty price per unit would be $3,727 ($600,000÷161). This sales price could then be applied to each unit repaired meeting the warranty criteria. The depot would not receive credit for units requiring depot level repair and not meeting the warranted TBO. If the units repaired operate as predicted, the total revenues earned will equal the projected total repair costs. If the repaired units operate more hours than expected before repair, the depot will "earn" additional revenues which may be recognized as a reliability improvement. However, if the repaired units have attained less hours than expected, the depot will not

"earn" sufficient revenue to cover expected operating costs, and higher prices will be required for the next fiscal period to recoup the losses.

It should be noted that this approach is only applicable to a failure distribution model based on pre-repair operating hours. Obviously, this approach will not adequately measure reliability improvements initially, but over an extended period, reliability improvements should become apparent.

Warranty Applications

Mock warranty applications were made for the KT-73 and LN-14 systems using the following specified parameters:

	LN-14	KT-73
Units Repaired	50	61
Population TBO	200 Hrs	250 Hrs
RTOK Rate	20%	55%
Failure Distribution	Exponential	Exponential

The units selected for the warranty application were LN-14s repaired in January and February 1976 and KT-73 units repaired in July and August 1976. For purposes of the mock warranty, KT-73 units requiring a Category I or II repair were grouped as RTOKs since a depot level repair was not required. Table 16 presents the expected and actual failure distributions for the warranted assets. Figures 10 and 11 graphically present the expected and actual failure distributions.

Table 16

WARRANTY FAILURE DISTRIBUTIONS

LN-14

Operating Hours	F(x)	Expected Failures	Actual Failures	Expected RTOKs	Actual RTOKs
0-100	.3935	20	26	4	3
101-200	.6321	12	6	2	2
201-300	.7769	7	6	1	2
301-400	.8647	4	3	1	
401-500	.9179	3	3	1	1
501-600	.9502	2	3	1	
601-700	.9698	1	1		
Over 700	.9999	1	2		
		50	50	10	8

KT-73

Operating Hours	F(x)	Expected Failures	Actual Failures	Expected RTOKs	Actual RTOKs
0-125	.3935	24	26	13	12
126-250	.6321	15	10	8	8
251-375	.7769	9	7	5	4
376-500	.8647	5	5	3	3
501-625	.9179	3	4	2	2
626-750	.9502	2	4	1	4
751-875	.9698	1	2	1	
875-1000	.9817	1	1	1	1
Over 1000	.9999	1	2		1
		61	61	34*	35*

Notes: * Category I & II repairs

$F(x) = 1 - e^{-\lambda t}$

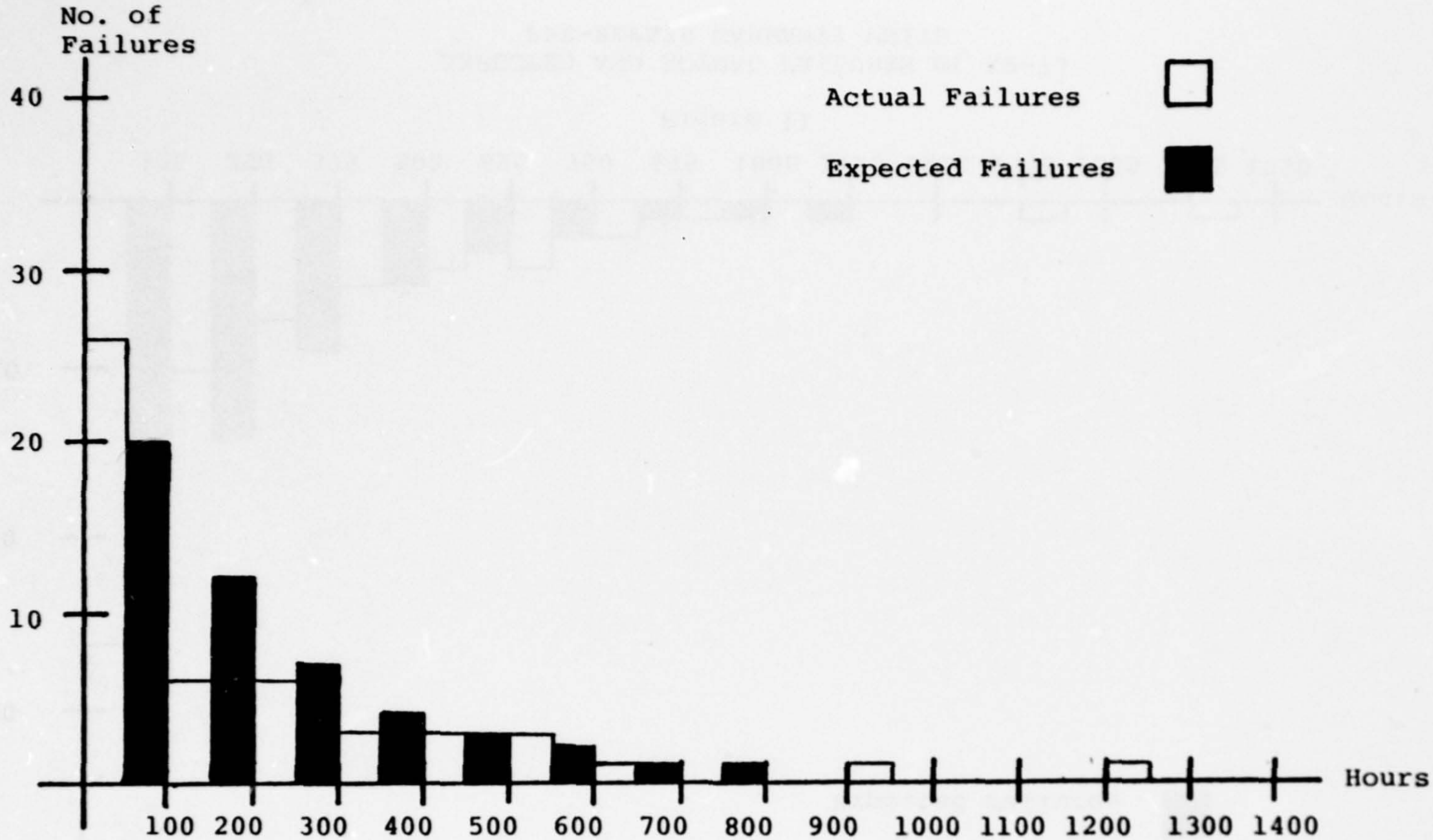

Figure 10

EXPECTED AND ACTUAL FAILURES OF LN-14
PRE-REPAIR WARRANTY UNITS

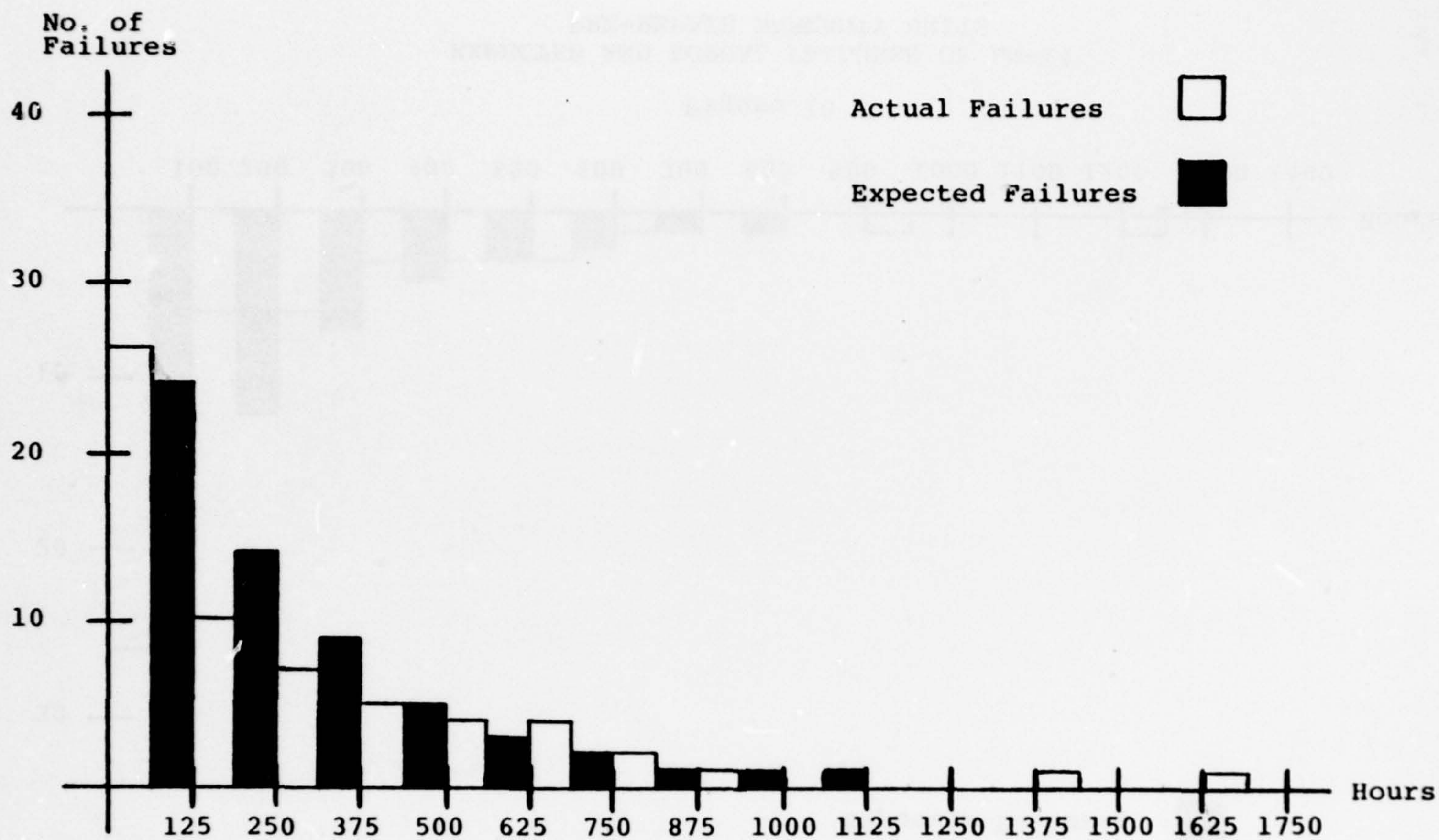

Figure 11

EXPECTED AND ACTUAL FAILURES OF KT-73
PRE-REPAIR WARRANTY UNITS

Using the costing methodology presented earlier in this chapter, the warranty sales prices were developed as presented in Table 17.

In both cases, as shown in Table 18 on page 99, the unfavorable variances were the result of more chargeable failures than expected. It should be noted, however, that the population TBOs were achieved in both cases (LN-14 - 204.7 hours and KT-73 - 286.541 hours).

Warranty Application to Post-Repair Operating Hours

While the DMS, AFIF procedures do not provide sufficient flexibility for a complete post-repair depot warranty policy, management attention should be directed to how well units are operating after repair. From this type of analysis, unfavorable failure trends can be detected and analyzed for maintenance management action. Using the same time periods selected for pre-repair warranty simulation, the repaired units were tracked until failure against the same parameters (LN-14 TBO - 200 hours and KT-73 TBO - 250 hours). As of 30 June 1977, 33 of the 50 LN-14 units had failed, and 36 of the 61 KT-73 units had failed. Figures 12 and 13, pages 100 and 101, present the actual and expected failure distributions. From these distributions, it can be seen that the repaired units are generally failing as expected, although the number of failures with less than the warranted operational hours are somewhat

Table 17

COMPUTATION OF WARRANTY SALES PRICES

LN-14

DMS, AFIF Unit Sales Price Without Profit/Loss Factor	$ 3,500
Workload	x 50
Total Costs to be Covered	$175,000
Expected Units Failing Warranty	20
Less: Expected RTOKs	(4)
Expected Chargeable Failures	16
Expected Successes	34
Warranty Unit Sales Price ($175,000 ÷ 34)	$ 5,147

KT-73

DMS, AFIF Unit Sales Price Without Profit/Loss Factor	$ 3,400
Workload	x 61
Total Costs to be Covered	$207,400
Expected Units Failing Warranty	24
Less: Expected RTOKs	(13)
Expected Chargeable Failures	11
Expected Successes	50
Warranty Unit Sales Price ($207,400 ÷ 50)	$ 4,148

Using these warranty sales prices, the revenues earned were as shown in Table 18.

Table 18

MOCK WARRANTY RESULTS

LN-14	
Units Meeting Warranty Criteria	
RTOKs ≤ 100 Hours	3
Failures > 100 Hours	24
	27
Revenues Earned (27 units x $5,147)	$138,969
Expected Costs	175,000
Variance	($ 36,031)
KT-73	
Units Meeting Warranty Criteria	
RTOKs ≤ 125 Hours	12
Failures > 125 Hours	35
	47
Revenues Earned (47 units x $4,148)	$194,956
Expected Costs	207,400
Variance	($ 12,444)

higher than might be expected. With this type of information, depot maintenance management personnel may wish to determine why the early failures are occuring and take appropriate corrective action.

LIFE CYCLE COST EFFECTS OF AN ORGANIC DEPOT WARRANTY

The goals of any warranty program should be two-fold--improve the reliability of the system and decrease the life cycle costs. While the major thrust of a commercial RIW application is to induce engineering

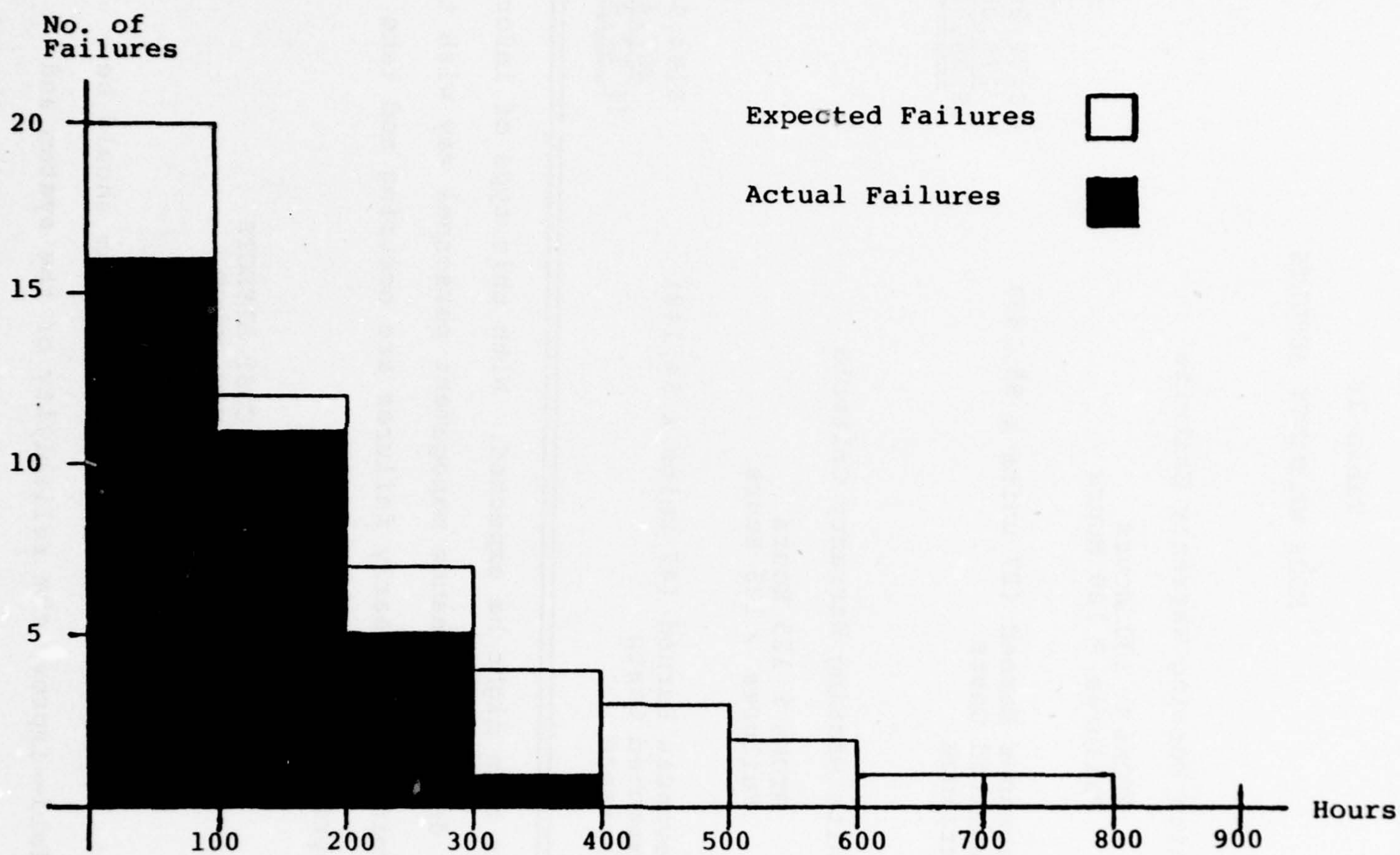

Figure 12

EXPECTED AND ACTUAL FAILURES OF LN-14 POST-REPAIR WARRANTY UNITS

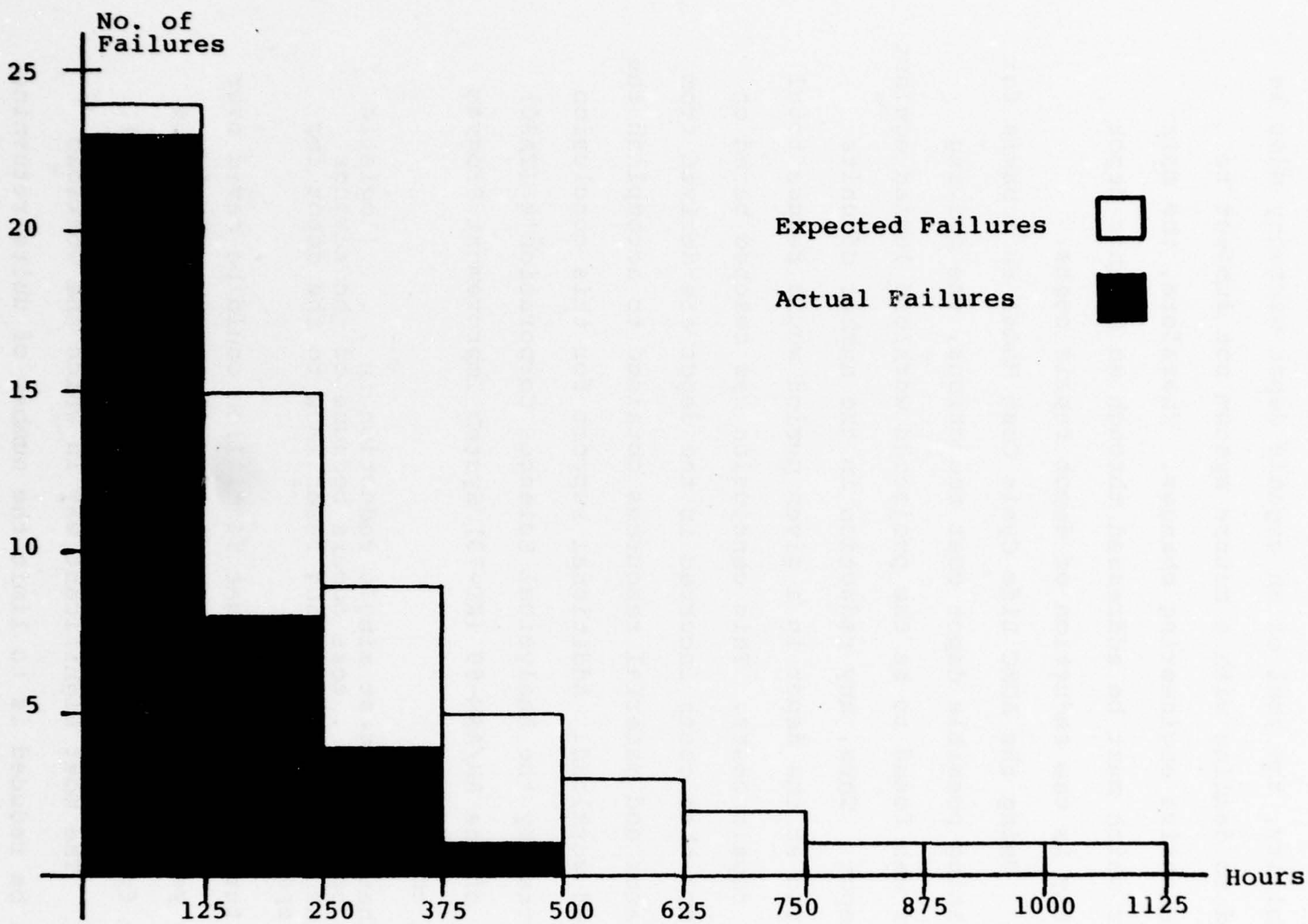

Figure 13

EXPECTED AND ACTUAL FAILURES OF KT-73 POST-REPAIR WARRANTY UNITS

changes during the initial period of operation to improve reliability, the goal of an organic depot warranty must be geared to dealing with a mature system not subject to comprehensive engineering changes. Therefore, the main factor which must be addressed through an organic depot warranty is the reduction of depot repair costs.

Using the AGMC Life Cycle Cost Model as a basis for evaluating possible depot cost reductions, the driving factor was found to be the projected workload levied against the depot. Thus, any reduction in the number of units received at the depot in a given period would reduce total depot repair costs. This conclusion was reached based on the fact that costs incurred in the depot are derived from the labor and material resources obtained to accomplish the planned workload. Additional support for this conclusion was noted by the Analytical Sciences Corporation's (TASC) Study of the AN/ASN-90 (KT-73) System Improvement Program which concluded

> that the largest single reduction in . . . [logistic support] . . . cost occurs because of the savings incurred from returning fewer IMUs to the depot for repair [21:43].

TASC further concluded that $4 million could be saved over a ten year period if the number of units returned to the depot from the field were reduced by 30 percent (21:44).

The most significant way in which the workload could be reduced is to limit the number of units returning

to the depot not requiring repair or requiring a repair which could have been accomplished at field level (21:44). While the application of a depot warranty in itself will not rectify this problem, it will force additional management attention to the RTOK problem in that RTOKs must be considered in developing the expected failure distribution and costing methodology. Additionally, as RTOK units are identified at the depot, reports could be processed to the using commands to identify the number of RTOK units and the costs associated with their turnaround.

While significant engineering design changes are not realistically possible on most systems repaired in organic depots, the engineering directorates of the depot repair activity can recommend changes in design, repair and test procedures, and maintenance policies. Using these changes in the same manner as engineering change proposals made by contractors under an RIW application, reliability improvements can then be measured by monitoring repaired assets under a warranty program. If significant cost savings (reduced maintenance costs at the depot and field) are achieved, proper recognition can then be documented through the Value Engineering Program or Resource Conservation Program.

CONCLUSIONS

An organic depot warranty application with costing implications is feasible within DMS, AFIF procedures if

applied to pre-repair operating hours. While this approach does not achieve an accurate short range assessment of reliability improvements, it does provide a management tool to evaluate operational reliability. It is also desirable to conduct post-repair reliability assessments in the context of a warranty application, although funding considerations are difficult because of failures occuring over several fiscal periods. The overall goals of an organic depot warranty should be to improve reliability and reduce costs, and an organic depot warranty can assist in focusing management attention in both areas.

CHAPTER VII

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FURTHER STUDY

The objective of this research was to develop a methodology for applying a warranty concept to an organic depot workload with the potential of increasing operational reliability and decreasing life cycle costs. To establish the basic methodology, research questions were formulated to address four key concepts required to develop a warranty methodology for aircraft inertial navigation units repaired by the Aerospace Guidance and Metrology Center (AGMC). While this study concentrated on the AGMC aircraft inertial navigation system workload, the techniques employed were applicable to any organic depot workload meeting the criteria indicated in the study.

The first research question evaluated the operational and equipment characteristics of the eight aircraft inertial navigation systems repaired by AGMC against the Reliability Improvement Warranty application criteria established by Balaban and Retterer of ARINC, Inc. Based on this evaluation, five of the eight systems were found to be inappropriate for an organic depot warranty application. Of the three systems which met the Balaban-Retterer criteria, one was arbitrarily eliminated because of a limited workload. The

two remaining systems (KT-73 and LN-14) were then evaluated against the second research question to determine if the units failed in conformance with recognized reliability probability distributions.

Using a random sample of KT-73 and LN-14 units repaired in 1975 and failed (returned to AGMC) by June 1977, it was determined that the units failed in accordance with an exponential distribution, one of the various recognized reliability probability distributions. As part of this portion of the evaluation, it was also noted that no significant difference existed in the operational times of the units relative to the degree of repair provided by AGMC. Finally, an evaluation of the pre-repair (prior to failure) operational times for units repaired during a six month period disclosed that the times were also exponentially distributed with no significant differences between the repair categories.

The third research question involved the determination of whether Depot Maintenance Service, Air Force Industrial Fund (DMS, AFIF) procedures were sufficiently flexible to accommodate the use of an organic depot warranty. An in-depth review of DMS, AFIF policies and procedures and discussions with operating personnel disclosed that sufficient flexibility existed within the DMS, AFIF to accommodate a depot warranty policy. While direct profits or losses could not be levied against the depot because of

long-run breakeven constraints, flexibility was available through profit and loss factors and costing techniques to establish the potential for meaningful management visibility of the costs involved in repairing poor performance units. However, to facilitate the application of a costing methodology, it was determined that the revenue and cost application would have to be applied to pre-repair operating times to preclude the problems of evaluating failures over a multi-year period. While this approach would not provide meaningful results of reliability improvements initially, over an extended period it would reflect reliability enhancements.

As part of the fourth research question, a mock warranty was applied to two months' workload to demonstrate a possible warranty approach with costing implications for management visibility. While this mock application was made using pre-repair operating times to facilitate the costing, it was also noted that a post-repair failure analysis was imperative to provide total management information. Finally, the life cycle cost implications of a depot warranty application were presented. It was concluded that the application of an organic depot warranty would increase the management visibility of units returned to the depot not requiring depot repair, and that any decrease in the generation of these units would reduce total logistics costs.

CONCLUSIONS

Based on the evaluations performed in consonance with the research questions, it was concluded that it is feasible to apply an organic depot warranty to selected aircraft inertial navigation systems repaired by AGMC. While the profit and loss implications of a commercial RIW are not directly possible within the DMS, AFIF, there is sufficient flexibility to permit the development of costing data for management visibility purposes. Finally, the potential exists to lower life cycle costs by reducing the number of units returned to the depot for repair.

Figure 14 presents a flowchart portrayal of the basic methodology developed by the researchers for an organic depot warranty application. This methodology includes the use of an application criteria test to screen potential candidates, the determination of the expected failure distribution, and the decision to use pre-repair or post-repair operational times. If pre-repair operational times are used, costing implications within the DMS, AFIF can be developed to provide management cost visibility. Using post-repair operational times, a costing methodology using DMS, AFIF procedures could not be developed, but the post-repair approach would provide management data as to how well the repaired units are performing. Finally, suggested management reports are presented to detail actual failure distributions, costs associated with units not meeting the warranty criteria, and RTOK units.

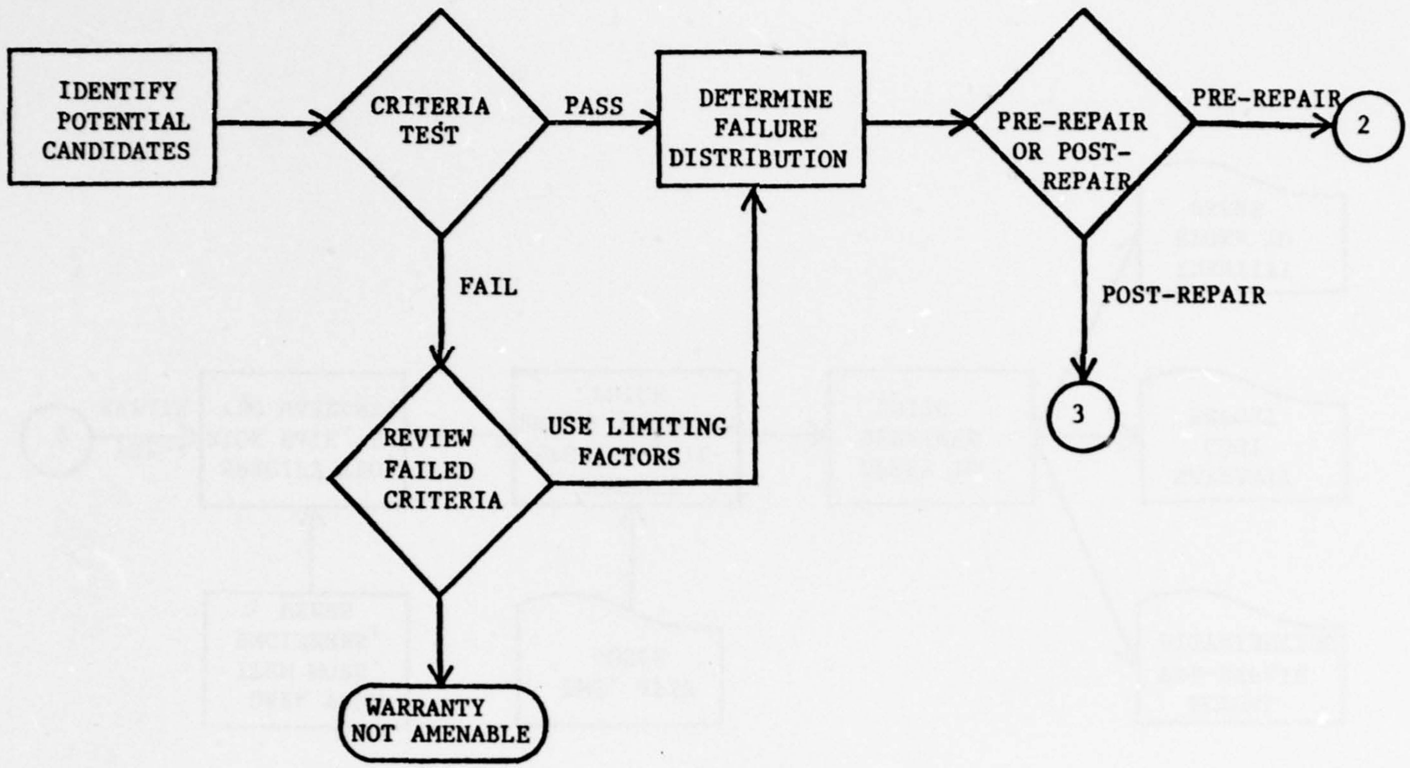

Figure 14

ORGANIC DEPOT WARRANTY METHODOLOGY

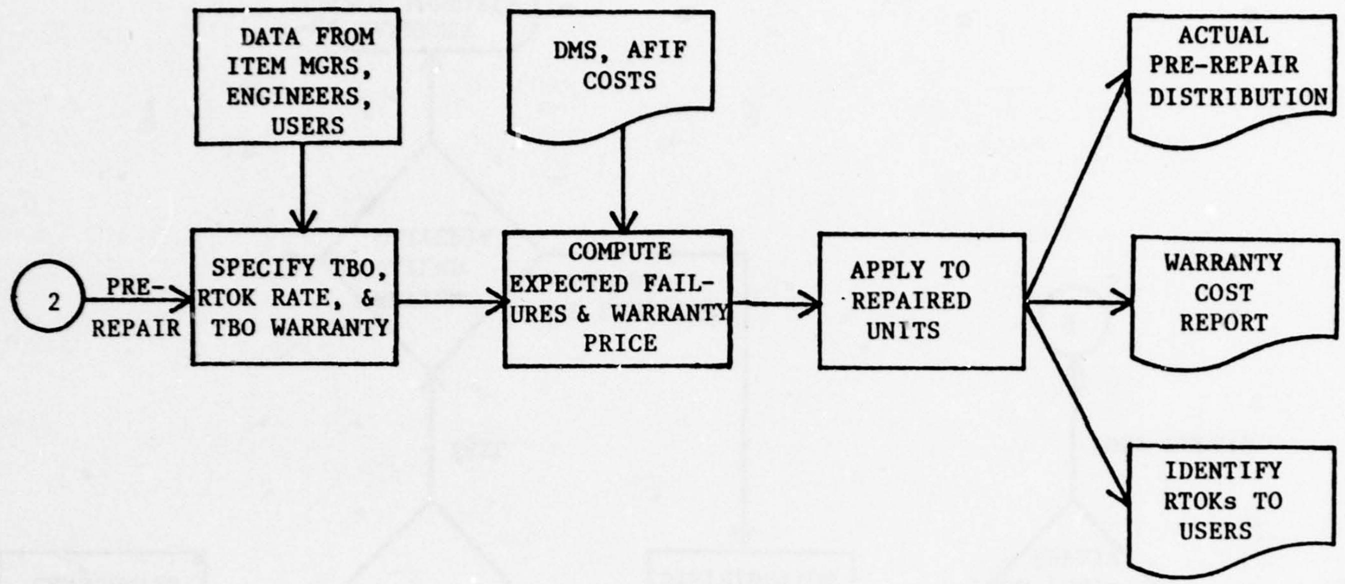

Figure 14 (continued)

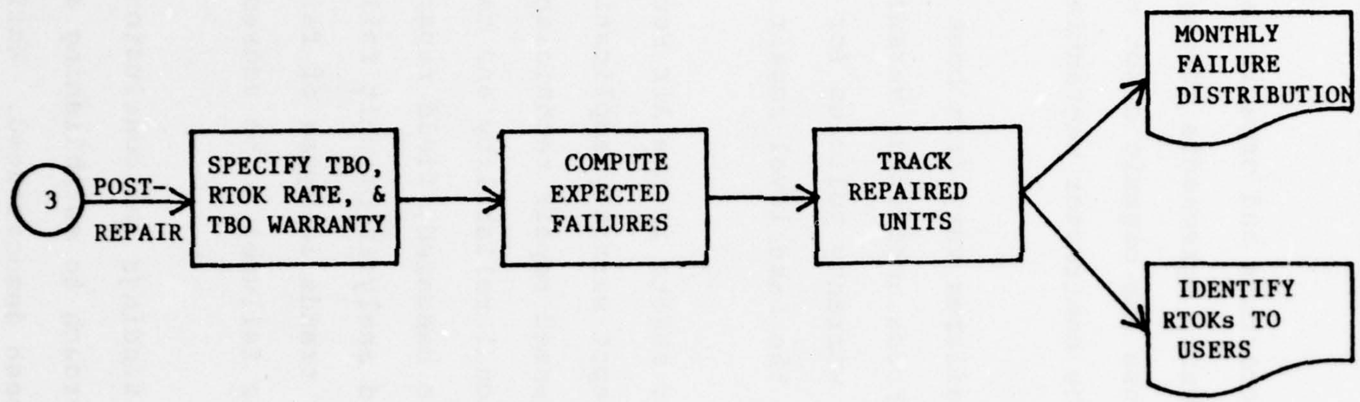

Figure 14 (continued)

RECOMMENDATIONS FOR FURTHER STUDY

This research disclosed several areas for further study. They are:

1. Would contractors and organic depot facilities be amenable to partnership agreements through which the contractor would license the organic depot to perform depot level repairs while the contractor warranties operational reliability?

2. Do unit failures vary from base to base or user to user (regular Air Force activities versus Air Reserve units)? Are separate warranty policies for each user required according to the base level repair capability per each user?

3. What other assets in the Air Force inventory are appropriate for depot warranty applications?

4. Would licensed repair technicians at field level enhance operational reliability and make it possible to apply warranties to unsealed, field reparable assets?

5. A detailed analysis of unit failures should be conducted to identify trends in types of failures to determine the specific failures to be addressed in a warranty application.

Based on the findings and conclusions presented in this research, an approach to establishing an organic depot warranty policy has been demonstrated. While some previous

research has been performed in this area, the researchers believe that this is the first approach to use failure probability distributions as the basis for the warranty policy. Using this approach, management will be able to better formulate expected failure distributions and therefore, reduce some of the uncertainty in the overall decision process.

APPENDIX A

DEFINITIONS AND ABBREVIATIONS

DEFINITIONS AND ABBREVIATIONS

Term/Abbreviation	Explanation
Aerospace Guidance and Metrology Center (AGMC)	An Air Force organic depot repair facility at Newark AFS, Ohio responsible for the depot level repair of inertial navigation systems; part of the Air Force Logistics Command.
Air Logistics Center (ALC)	An Air Force Logistics Command activity responsible for the management (including depot level repair) of designated weapon systems.
Authorized Repair Unaccomplished at Base (ARUB)	An inertial system received at AGMC for which the only maintenance actions required were those authorized to be performed in the field (base level).
Aviation Supply Office (ASO)	A. U. S. Navy activity responsible for the management of designated weapon systems.
Category I, II, III, IV	Repair categories of the KT-73 Inertial Measurement Unit I - retest OK II - replacement of external modules (AR6, AR7, AR8, and/or AR9) III - repair or replacement of components within the sealed unit but external to the cluster IV - repair or replacement of the cluster or its components

Term/Abbreviation	Explanation
Depot Maintenance Service, Air Force Industrial Fund (DMS, AFIF)	A subdivision of the Air Force Industrial Fund responsible for the funding of depot level repair actions by organic facilities and contractors.
Elapsed Time Indicator (ETI)	A device attached to the inertial navigation system which records operational hours.
Inertial Navigation System (INS)	An avionics electronic system which provides precise navigational data based on reading from fixed gyroscopes, velocity-meters, and accelerometers. For purposes of this research, inertial measurement units and inertial reference sets will be considered as synonymous.
Life Cycle Costs (LCC)	The total cost to the Government of acquisition and ownership of equipment over its full life.
Line Replaceable Unit (LRU)	An avionics system which can be removed intact from the weapon system.
Mean	Sum of values of a population or sample divided by the number of observations.
Mean Time Between Failure (MTBF)	A measure of reliability computed by dividing weapon system operational time by the number of system removals.

Term/Abbreviation	Explanation
Ogden Air Logistics Center (OO-ALC)	An Air Force Logistics Command ALC located at Hill AFB, Utah.
Oklahoma City Air Logistics Center (OC-ALC)	An Air Force Logistics Command ALC located at Tinker AFB, Oklahoma.
Parameters	Statistical values describing a population. Parameters are constants and are expressed as the mean, variance, and standard deviation.
Population	Each and every member of some grouping.
Random Sampling	A statistical methodology of extracting a sample unit from a population so that each unit in the population has an equal chance of selection.
Reliability	The probability that a device will operate adequately for a given period of time in its intended application.
Reliability Improvement Warranty (RIW)	A procurement technique in which the contractor guarantees the operational characteristics of a system within stated parameters.

Term/Abbreviation	Explanation
Retest OK (RTOK)	Refers to an inertial system received at AGMC for which no maintenance actions were necessary in order that it be declared serviceable.
Repair Categories	A classification of the "depth" of repair of an inertial system.
Sacramento Air Logistics Center (SM-ALC)	An Air Force Logistics Command ALC located at McClellan AFB, California.
San Antonio Air Logistics Center (SA-ALC)	An Air Force Logistics Command ALC located at Kelly AFB, Texas.
Shop Replaceable Unit (SRU)	A component of an LRU which can be replaced at field level maintenance activities.
SIMFIT	A computer technique which analyzes sample data and fits the data to various probability distributions.
Standard Deviation	The square root of the population variance.
Time Between Overhaul (TBO)	The time elapsed on an inertial navigation system between a depot level repair and a depot level failure; computed from ETI readings.

Term/Abbreviation	Explanation
Variable	A condition or characteristic of an item or process which can vary under specified conditions.
Variance	The sum of the square of deviation of the individual observations from the arithmetic mean of those observations divided by the number of observations.
Warner-Robins Air Logistics Center (WR-ALC)	An Air Force Logistics Command ALC located at Robins AFB, Georgia.

APPENDIX B

BALABAN-RETTERER APPLICATION CRITERIA MATRIX

MODIFIED BALABAN-RETTERER RIW APPLICATION

Criteria Matrix (Note 1)

EQUIPMENT FACTORS

Criteria	Rationale	Index (Note 2)	Test Criteria
1. Equipment maturity at an appropriate level.	Warranty should not be used for items that are considered to be developmental because of the inherent large risks.	1	Is the weapon system operational? How long has the system been operational? Do system engineers consider the inertial system at a mature level?
2. Control of unauthorized maintenance can be exercised.	Unauthorized maintenance of a warranted item is normally excluded in a reliability-improvement warranty.	1	Is the system basically a sealed unit?
3. Unit is field testable.	Lack of field testability can greatly increase cost of support because of the requirement for additional spares plus the added cost of testing a good unit.	1	Can the system be tested and/or repaired at field level?
4. Unit can be properly marked or labeled to signify existence of warranty coverage.	The most effective means of communicating the existence of warranty coverage is suitable marking of the item itself.	1	Can the system be externally labeled?

EQUIPMENT FACTORS (continued)

Criteria	Rationale	Index (Note 2)	Test Criteria
5. Unit is amenable to reliability and maintainability improvements and changes.	A primary objective of warranty is reliability and maintainability growth.	1	Do system engineers believe that system reliability can be improved?
6. Unit is reasonably self-contained.	System failures should be isolated to the unit.	2	Is the system failure isolated to the unit?
7. Unit can be readily transported to the repair facility.	The most cost-effective method of providing warranty service is to make use of centralized repair facilities.	2	Is the system shipped to a depot for repair?
8. Unit has a high level of ruggedization.	Delicate units highly subject to failure from handling and shipping may lead to an unacceptably high frequency of warranty exclusions.	2	Do the system engineers believe failures are unnecessarily induced by rough handling and shipping?
9. Unit maintenance is highly complex.	Maintenance requires highly trained personnel and extensive test equipment.	3	Do the system engineers consider the system's maintenance to be highly complex?
10. An elapsed time indicator can be installed on the equipment.	ETIs permit accurate measurement of operating time.	1	Is the system equipped with an ETI?

OPERATIONAL FACTORS

Criteria	Rationale	Index	Test Criteria
1. Use environment is known or predictable.	Information on the use environment is required to evaluate failures.	1	Is the operational environment known?
2. Equipment operational reliability and maintainability are predictable.	Estimating reliability is important for determining the expected number of failures and estimating repair costs.	1	Can the times between overhaul be fitted to a known probability distribution? This will be addressed as part of the reliability assessment.
3. Equipment has a high operational utilization rate.	Equipment that remains dormant for long periods and has limited shelf life may not receive sufficient usage to make warranty worthwhile.	2	Is the system operationally required for mission accomplishment by the weapon system?
4. Warranty administration can be efficiently accomplished.	The success of a warranty program requires that careful attention be given to the plan for warranty administration.	2	Are records readily available to determine reliability assessments and failure analyses?
5. Unit reliability and usage levels are amenable to warranty application.	Units that are highly reliable may not fail often enough to justify a warranty.	2	Does the AGMC Reliability Trend Report indicate excessive failures with low times between overhaul?
6. Operating time exposure is known or predictable.	The number of failures is directly related to the amount of usage.	2	Is the system tracked as part of the AGMC Reliability Trend Report?

OPERATIONAL FACTORS (continued)

Criteria	Rationale	Index	Test Criteria
7. Provision has been made for computing the unit's mean time between failure.	Comparison of the observed operational characteristics to the guaranteed MTBF is the key element in determining warranty compliance.	1	Are records available to determine operational times between repairs for specific serially numbered units?

Note 1: The Balaban-Retterer matrix also contains criteria factors relating to system procurement or contractor actions which were not considered appropriate for this research as the systems under study are already in use and repaired at an organic depot.

Note 2: Importance Index: 1 - Major
2 - Secondary
3 - Minor

APPENDIX C

RELIABILITY ASSESSMENT DATA

KT-73 POST-REPAIR SAMPLE UNITS

SERIAL NUMBER	ETI OUT	ETI IN	TBO	DATE SHIP	DATE RETURN	REPAIR CATEGORY OUT	REPAIR CATEGORY IN
AFO 004	1180	1187	7	5041	5070	4	2
005	1816	1834	18	5289	6019	2	1
006	1275	1393	118	5134	6288	1	-
009	1430	1589	159	5274	6086	4	2
020	1329	1462	133	5161	5346	2	4
022	1456	1824	368	5022	6021	1	4
025	1391	1483	92	5234	6008	3	1
028	1082	1375	293	5118	6138	2	4
087	1017	1075	58	5129	5167	1	1
040	1038	1164	126	5272	6133	4	4
042	1411	1611	200	5293	6154	4	2
047	1766	2204	438	5121	6204	2	2
049	1243	1487	244	5230	6169	4	3
067	106	618	52	5098	6092	1	3
BYJ 024	2697	3032	335	5204	6306	2	1
066	126	134	8	5161	5213	1	3
081	2165	2284	119	5114	5245	2	4
107	229	234	5	5304	5364	1	1
112	1954	2336	382	5126	6069	4	1
115	1669	1670	1	5176	5204	2	1
117	1130	1400	270	5119	6122	1	4
126	1461	1546	85	5190	5275	4	2
132	1645	1646	1	5245	5259	2	2
134	1773	1778	5	5129	5216	2	3
160	1220	1304	24	5030	5127	1	2
161	1827	2156	329	5087	6265	4	3
167	1678	1922	244	5140	6016	1	1
173	2170	2170	0	5009	5041	4	2
184	1722	1789	67	5288	6009	2	1
192	1654	2095	441	5067	6352	2	3
193	33	82	49	5020	5143	3	2
199	1970	2197	227	5007	6076	1	3
201	1638	1778	140	5030	5204	1	1
203	1786	2121	335	5052	5187	1	2
221	1592	1885	293	5022	6016	2	4
239	1618	2167	549	5101	6259	2	2
246	1649	1714	65	5114	6196	1	1
249	2040	2121	81	5262	5338	1	2
251	1839	2123	284	5027	5259	2	1
258	1818	1835	17	5151	5220	1	3
262	1534	2143	609	5070	6245	1	1
263	1814	1834	20	5275	5352	1	1
265	1061	1153	92	5231	6069	4	3

KT-73 POST-REPAIR SAMPLE UNITS
(continued)

SERIAL NUMBER	ETI OUT	ETI IN	TBO	DATE SHIP	DATE RETURN	REPAIR CATEGORY OUT	REPAIR CATEGORY IN
BYJ 266	1418	1711	293	5315	6275	4	3
269	1754	1844	90	5261	6345	2	3
279	2120	2490	370	5232	6247	1	3
280	1099	1466	367	5027	6051	3	1
281	1064	1382	318	5055	6286	1	3
313	1372	1934	562	5015	7001	4	2
323	991	1058	67	5248	6026	1	3
330	1589	1592	3	5176	5246	4	2
331	1166	1609	443	5350	7068	4	1
CCL 008	840	1098	258	5251	7006	4	4
024	2386	2562	176	5189	6061	4	1
050	1267	1753	486	5083	6254	4	3
060	2520	2825	305	5178	6215	4	-
115	1051	1081	30	5098	5142	1	1
172	2594	2809	215	5346	6296	3	3
186	2279	2290	11	5262	6076	4	2
194	1730	2037	307	5015	5293	4	4
213	2256	2280	24	5262	5310	4	2
219	127	295	168	5141	5230	4	3
242	1466	1661	195	5009	5133	1	3
252	962	963	1	5225	5297	3	2
258	2380	2382	2	5304	5364	1	3
261	1719	1766	47	5296	6014	4	2
336	1686	1755	69	5028	5114	4	4
346	1648	2504	856	5027	7103	4	1
354	247	408	161	5322	6124	2	2
360	1648	1718	70	5020	5174	1	1
363	1410	1454	44	5330	6062	4	1
365	1191	1458	267	5070	5276	2	4
369	1520	1777	257	5273	6198	1	4
383	1524	1553	29	5328	6314	4	4
384	1247	1248	1	5181	5265	2	2
CSG 021	2403	2486	83	5291	6084	3	2
DUX 001	1280	1349	69	5258	5346	2	2
003	891	1233	342	5253	6279	1	2
010	1253	1281	28	5296	6250	2	1
011	976	1432	456	5153	7077	4	3
014	1064	1082	18	5118	5143	3	1
026	37	665	628	5035	6076	4	1
030	913	1093	180	5041	5311	2	4
036	746	762	16	5015	5062	4	1
036	803	829	26	5083	5110	1	1

KT-73 POST-REPAIR SAMPLE UNITS
(continued)

SERIAL NUMBER	ETI OUT	ETI IN	TBO	DATE SHIP	DATE RETURN	REPAIR CATEGORY OUT	REPAIR CATEGORY IN
DUX 067	983	1344	361	5197	6114	2	1
071	834	974	140	5113	5220	2	2
077	986	1022	36	5230	5314	4	4
088	921	1310	389	5037	6086	1	4
089	1164	1255	91	5120	5352	2	4
091	1009	1422	413	5170	6347	2	1
DUY 010	782	945	163	5053	5328	3	3
016	847	1141	294	5067	6216	2	1
056	644	772	128	5127	5325	1	3
065	588	688	100	5191	5346	3	1
PSO 003	1361	1367	6	5098	6034	4	1
004	1182	1333	151	5176	5356	3	1
005	2517	2701	184	5241	6219	3	1
014	2760	2769	9	5150	5202	3	1
018	1449	1991	542	5204	7012	2	4

KT-73 PRE-REPAIR UNITS

July-December 1976

SERIAL NUMBER	DATE SHIPPED	TBO	SERIAL NUMBER	DATE SHIPPED	TBO
AFO 008	76363	458	BYJ 171	76259	20
009	76254	57	172	76264	148
010	76238	344	177	76355	299
020	76219	30	178	76219	355
021	76198	681	179	76343	890
024	76267	85	185	76243	672
026	76334	344	189	76194	571
028	76236	11	195	76320	214
029	76301	895	199	76198	79
034	76355	933	203	76194	335
035	76216	390	207	76222	163
038	76212	93	207	76306	33
038	76300	10	207	76358	13
040	76208	126	213	76306	265
043	76223	1910	215	76210	429
044	76198	918	215	76306	21
044	76254	15	224	76315	109
047	76216	439	225	76183	98
052	76260	146	229	76323	192
054	76212	504	231	76278	172
062	76278	674	239	76272	549
065	76303	110	240	76196	12
074	76321	106	240	76345	268
087	76352	18	242	76317	26
091	76348	61	246	76315	78
092	76363	76	251	76219	149
BYJ 005	76251	69	256	76301	156
024	76313	335	259	76323	995
046	76315	75	262	76258	609
085	76233	558	266	76289	292
085	76303	1	269	76355	90
086	76317	631	276	76320	457
087	76216	153	279	76266	370
094	76342	1211	279	76324	1
107	76314	211	280	76231	83
117	76252	7	281	76300	318
128	76316	1169	287	76282	698
142	76329	148	287	76336	2
149	76258	630	299	76328	497
151	76257	1283	304	76231	10
158	76306	123	305	76303	51
161	76278	329	307	76226	3
170	76218	658	307	76280	2
171	76198	723	316	76247	0

KT-73 PRE-REPAIR UNITS
(continued)

SERIAL NUMBER	DATE SHIPPED	TBO
BYJ 316	76352	80
321	76201	289
323	76240	19
323	76296	14
327	76265	73
328	76233	20
345	76236	27
345	76334	57
347	76272	670
349	76252	445
366	76278	748
366	76349	0
CCL 013	76334	446
027	76196	24
050	76273	486
050	76336	11
102	76254	452
114	76198	1379
131	76334	301
132	76210	840
156	76264	106
172	76309	216
205	76306	967
208	76342	25
238	76205	278
252	76204	6
272	76201	3
273	76247	31
273	76342	14
288	76324	365
297	76335	114
334	76316	221
337	76295	16
354	76286	23
361	76216	123
364	76306	116
369	76216	257
369	76308	51
371	76226	40
371	76295	1
371	76349	10
377	76303	723
380	76268	192
383	76355	29
384	76295	199

SERIAL NUMBER	DATE SHIPPED	TBO
DUX 001	76246	228
003	76303	342
010	76261	28
012	76205	472
012	76260	0
017	76208	10
018	76225	13
031	76348	38
036	76303	3
039	76238	127
050	76205	3
050	76287	18
055	76240	33
055	76293	0
056	76191	138
056	76274	49
065	76240	160
070	76233	71
071	76323	366
081	76301	138
088	76195	389
088	76244	2
088	76324	84
089	76191	148
089	76323	6
091	76296	413
DUY 016	76231	294
030	76243	816
056	76218	34
EWC 001	76212	54
010	76288	15
023	76224	56
PS 004	76246	99
005	76233	185
009	76210	540
009	76306	49
014	76205	132
014	76323	13
017	76336	1016

Mean = 265.2965

Variance = 106014.818

Standard Deviation = 325.5992

LN-14 POST-REPAIR SAMPLE UNITS

SERIAL NUMBER	ETI OUT	ETI IN	TBO	DATE SHIP	DATE RETURN	REPAIR CATEGORY OUT	REPAIR CATEGORY IN
148	813	975	162	75052	75335	D	D
148	1006	1317	311	75352	76343	D	R
189	1227	1243	16	75294	76065	R	D
190	1486	1511	25	75093	76035	D	D
194	1932	2214	282	75183	76322	D	D
203	1821	2008	187	75181	76183	D	D
212	1980	2304	324	75139	75287	R	D
214	778	788	10	75017	75183	D	D
208S	1345	1345	0	75143	75225	R	R
219S	1193	1478	285	75072	77161	D	-
240S	1016	1026	10	75342	76162	R	R
3003	1205	1246	41	75031	75219	D	D
3006	1674	1841	167	75329	77039	D	D
3013	1342	1797	455	75259	77046	R	D
3016	1597	1616	19	75282	76142	D	D
3017	1587	1624	37	75057	76107	D	R
3024	1250	1560	310	75178	77060	R	D
3029	1176	1488	312	75321	77060	R	D
3030	1207	1355	148	75151	76162	D	D
3035	1106	1658	552	75057	77038	D	-
3036	1124	1160	36	75246	76068	D	D
3037	1370	1473	103	75343	76232	D	D
3042	909	929	20	75136	76035	D	R
3048	869	899	30	75104	75183	D	D
3048	910	1249	339	75195	76197	D	R
3062	1485	1591	106	75052	77005	D	D
3063	1192	1311	119	75303	76216	D	D
3070	683	806	123	75241	76271	D	D
3074	554	1187	633	75170	77096	R	D
3075	2136	2271	135	75258	76154	D	D
3076	1187	1237	50	75142	75342	D	D
3083	1366	1399	33	75311	76098	D	R
3084	966	1006	40	75274	76103	D	D
3086	1509	1559	50	75169	76163	D	D
3088	769	799	30	75126	76044	D	D
3089	1329	1342	13	75079	76002	D	D
3095	1070	1186	116	75252	76126	D	D
3107	1526	1613	87	75178	76012	R	R
3168	2097	2105	8	75240	75291	R	D
3179	999	1182	183	75133	76134	D	R
3211	1265	1731	466	75267	77061	D	D
3214	170	1534	364	75086	76288	D	R

LN-14 POST-REPAIR SAMPLE UNITS
(continued)

SERIAL NUMBER	ETI OUT	ETI IN	TBO	DATE SHIP	DATE RETURN	REPAIR CATEGORY OUT	REPAIR CATEGORY IN
3228	847	1055	208	75226	77125	D	D
3231	1127	1204	77	75064	76012	D	D
3608	1360	1573	213	75154	77153	D	D
3612	1127	1144	17	75038	75315	D	D
3617	1761	1798	37	75166	76062	D	R
3620	1347	1375	28	75160	75223	D	D
3630	1056	1375	319	75209	76322	R	D
3631	1143	1196	53	75247	76204	D	D
3633	796	1086	290	75261	77161	D	-
3638	818	988	170	75317	76223	D	D
3650	1043	1142	99	75304	76135	D	D
3665	663	753	90	75309	76251	D	D
10182	1577	1660	83	75304	76163	D	D
10184	1612	1723	111	75057	76064	D	R
10205	1494	1509	15	75265	76037	D	D
184M3	1541	1558	17	75351	76132	D	R
33069	1648	1657	9	75199	75289	D	D
33078	289	359	70	75115	76002	D	D
33081	1801	2078	277	75262	76188	D	R
33084	1386	1639	253	75210	76216	R	D
33095	1973	2000	27	75365	76226	D	R
33097	1717	1803	86	75042	75324	D	D
33100	2023	2086	63	75353	76154	D	D
33103	1926	1950	24	75356	76184	R	D
33105	1440	1497	57	75325	76100	D	D
33117	1093	1104	11	75224	75287	D	D
33118	1437	1995	558	75031	77094	D	-
33120	1378	1514	136	75219	76062	D	D
33137	1381	1625	244	75224	76131	D	D
33146	1330	1373	43	75120	75342	D	D
33147	1392	1448	56	75125	76013	D	D
33153	1359	1482	123	75085	76048	D	D
33159	1690	1896	206	75189	76161	D	D
33163	903	952	49	75134	76034	D	D
33165	2000	2165	165	75332	77060	D	D
33166	1453	1669	216	75358	77161	D	-
33171	807	837	30	75350	76183	D	D
33174	1710	1766	56	75296	76153	D	D
33177	1350	1366	16	75343	76127	D	R
33180	1550	1602	52	75135	76070	D	D
33186	1891	1957	66	75171	76154	D	D

LN-14 POST-REPAIR SAMPLE UNITS
(continued)

SERIAL NUMBER	ETI OUT	ETI IN	TBO	DATE SHIP	DATE RETURN	REPAIR CATEGORY OUT	REPAIR CATEGORY IN
33187	1647	1720	73	75168	76005	R	D
33193	1217	1496	279	75213	76233	D	D
33198	1619	1738	119	75302	76271	D	D
33200	1186	1477	291	75108	77125	D	D
33233	1175	1308	133	75041	76019	R	D
33236	1145	1157	12	75315	76019	D	D
103005	1668	1680	12	75050	75155	D	D
103005	1714	1933	219	75166	76104	D	D
103129	881	996	115	75195	76183	D	D
103147	706	779	73	75181	76016	D	D
103156	943	1461	518	75055	77130	D	D
103157	1292	1337	45	75030	75315	R	R
103201	1083	1232	149	75317	76190	D	R
103209	648	678	30	75318	76124	D	D
103212	1302	1332	30	75162	76042	D	D
133122	1240	1259	19	75020	75143	R	D
161SP25	1250	1460	210	75251	77062	D	R

Following 85 failed units added to sample in order to conduct t-statistic test in Table 12, Chapter IV.

158	1734	1970	236	75267	77061	D	D
173	1170	1210	40	75195	76043	D	D
212	2318	-	-	75301	76068	D	D
213	1463	1556	93	75181	76075	D	D
214	830	1354	534	75203	77095	D	D
251	1331	1345	14	75204	76061	D	D
199S	1568	1723	155	75205	76215	R	D
202S	1846	1928	82	75227	76162	R	R
208S	1357	1464	107	75230	77153	R	D
215S	1608	1810	202	75163	76301	D	D
229S	735	929	194	75321	77060	D	D
240S	988	996	8	75083	75335	D	R
3001	1873	2285	412	75181	76229	D	D
3003	1272	1417	145	75252	77026	D	D
3007	315	333	18	75239	76069	D	D
3009	1258	1422	164	75127	76061	D	R
3012	1571	1740	169	75237	76322	D	D
3020	1586	1642	56	75211	77041	D	D
3026	1240	1325	85	75212	76111	D	R
3028	1577	1685	108	75332	76093	D	D
3037	1307	1325	18	75021	75315	R	D
3039	1188	1538	350	75295	77094	D	D

LN-14 POST-REPAIR SAMPLE UNITS
(continued)

SERIAL NUMBER	ETI OUT	ETI IN	TBO	DATE SHIP	DATE RETURN	REPAIR CATEGORY OUT	REPAIR CATEGORY IN
3046	1079	1107	28	75358	76037	D	D
3057	1269	1269	0	75332	77094	D	R
3061	1079	1334	255	75113	76161	D	D
3082	1387	1427	40	75135	76070	D	R
3092	1015	1145	130	75258	77004	D	D
3099	1417	1427	10	75101	75219	D	D
3121	1565	1785	220	75304	76215	D	D
3173	1049	1087	38	75057	75338	-	D
3173	1105	1294	189	75345	76222	D	D
3180	790	821	31	75273	76040	R	R
3199	1256	1505	249	75232	76223	D	D
3202	529	633	104	75198	76033	D	D
3208	1050	1142	92	75212	76162	D	R
3210	974	1009	35	75259	76063	D	D
3603	1005	1489	484	75077	77123	D	D
3606	1427	1461	34	75301	76162	D	D
3609	1358	1481	123	75226	76112	D	D
3610	1673	1801	128	75183	76071	D	D
3612	1158	1332	174	75329	77161	D	-
3613	841	865	24	75118	76015	D	D
3620	1387	1654	267	75238	77094	D	D
3624	1380	1408	28	75350	76153	R	D
3629	1430	1520	90	75238	76124	D	D
3633	764	773	9	75076	75246	R	D
3634	968	1228	260	75069	77004	R	D
3647	634	776	142	75247	76253	D	D
3651	1082	1277	195	75132	76040	D	R
3652	1226	1329	103	75211	76110	D	D
3664	1354	1635	281	75073	77157	R	-
3666	744	800	56	75365	76132	R	R
3670	1612	1663	51	75211	76065	D	R
10169	1833	2194	361	75056	76154	R	D
10178	1928	1974	46	75358	76131	D	D
10185	1260	1504	244	75213	77005	D	D
10196	2086	2255	169	75330	77136	D	D
10202	1591	1643	52	75302	76125	D	D
203M6	1511	1589	78	75317	76153	D	D
33065	1811	1968	157	75148	76071	D	D
33071	821	1082	261	75160	77161	D	-
33084	1356	1356	0	75148	75205	D	R
33097	1832	1918	86	75332	76278	D	D
33111	1990	2098	108	75237	76033	D	D

LN-14 POST-REPAIR SAMPLE UNITS
(continued)

SERIAL NUMBER	ETI OUT	ETI IN	TBO	DATE SHIP	DATE RETURN	REPAIR CATEGORY OUT	REPAIR CATEGORY IN
33117	1133	1329	196	75304	76197	D	D
33125	2076	2575	499	75108	77157	D	-
33126	1816	2010	194	75069	77006	D	D
33129	866	866	0	75209	75262	D	R
33129	879	893	14	75267	75324	R	R
33129	911	942	31	75336	76271	R	D
33156	1064	1173	109	75365	76322	D	D
33161	1581	1738	157	75234	76127	D	D
33183	1953	336	2289	75178	77130	D	-
33189	1484	1919	435	75273	77161	R	-
33197	1946	1972	26	75296	76162	D	D
33206	828	1992	164	75071	76135	D	D
103140	672	808	136	75267	76322	D	D
103148	16	30	14	75200	75276	D	D
103148	58	65	7	75291	76048	D	D
103193	950	965	15	75220	76007	R	D
103206	591	704	113	75356	76315	D	R
203S58	991	1246	255	75296	76219	D	R
305614	1151	1178	182	75343	76253	D	D
305914	1482	1671	189	75294	76245	D	D
153SP24	717	771	54	75255	76063	R	D

LN-14 PRE-REPAIR UNITS

July-December 1976

SERIAL NUMBER	DATE SHIPPED	TBO	SERIAL NUMBER	DATE SHIPPED	TBO
148	76351	311	3199	76265	249
180	76191	683	3210	76288	49
180	76348	13	3214	76295	364
194	76332	282	3216	76203	494
197	76203	108	3602	76329	511
203	76267	187	3606	76257	34
212	76226	311	3610	76247	62
1945	76335	45	3615	76205	40
1995	76216	155	3617	76260	26
2025	76288	49	3624	76351	26
2155	76313	202	3631	76216	53
3001	76272	412	3631	76303	25
3012	76337	169	3638	76232	170
3016	76356	38	3647	76271	142
3017	76244	26	3652	76260	32
3030	76184	148	3655	76202	262
3030	76335	33	3658	76229	34
3037	76335	103	3659	76316	91
3038	76322	27	3660	76324	440
3048	76204	339	3665	76259	90
3050	76201	102	3666	76273	46
3050	76357	32	10174	76279	59
3060	76260	621	10184	76289	133
3063	76280	119	10192	76253	18
3070	76357	123	10193	76258	378
3072	76236	359	10205	76304	130
3073	76264	29	196M5	76300	131
3077	76243	35	33038	76303	282
3078	76198	26	33060	76356	16
3081	76273	19	33065	76273	9
3083	76264	10	33067	76279	11
3084	76303	53	33069	76245	14
3085	76237	972	33069	76313	14
3087	76351	11	33075	76278	350
3089	76348	181	33081	76195	277
3097	76349	33	33084	76244	253
3107	76226	181	33095	76233	27
3121	76231	220	33095	76303	33
3128	76260	511	33097	76323	86
3162	76342	675	33098	76232	33
3170	76265	312	33100	76216	63
3173	76236	189	33103	76216	24
3182	76236	173	33111	76239	70

LN-14 PRE-REPAIR UNITS
(continued)

SERIAL NUMBER	DATE SHIPPED	TBO
33117	76204	196
33119	76252	583
33120	76293	8
33129	76301	31
33137	76357	34
33143	76191	326
33143	76313	10
33146	76211	155
33150	76324	600
33156	76334	109
33162	76342	107
33171	76191	30
33180	76198	13
33180	76363	13
33181	76216	314
33191	76244	279
33197	76205	26
33198	76278	119
33204	76341	734
33233	76244	133
33236	76344	249
103129	76191	115
103140	76341	136
103147	76315	150
103158	76238	163
103178	76344	1052
103185	76243	78
103193	76337	59
103201	76198	149
103201	76337	17
103206	76322	113
103207	76314	13
103212	76212	22
103220	76195	88
203558	76225	255
305614	76280	27
305914	76260	189
172SP27	76211	463
3075	76182	135

Mean = 174.452

Variance = 39413.9457

Standard Deviation = 198.529

APPENDIX D

MOCK WARRANTY DATA

KT-73 MOCK WARRANTY UNITS

SERIAL NUMBER	PRE-REPAIR TBO	REPAIR CATEGORY	DATE SHIP	ETI OUT	DATE RETURN	ETI IN	POST-REPAIR TBO	REPAIR CATEGORY
AFO 021	681	1	76198	1712				
AFO 038	93	Depot	76212	1581	76281	1591	10	2
AFO 040	126	Depot	76208	1268	76343	1398	130	Depot
AFO 044	918	1	76198	1431	76245	1446	15	2
AFO 054	504	1	76212	1594				
BYJ 171	723	1	76198	2608	76247	2627	19	1
BYJ 189	571	Depot	76194	2375				
BYJ 199	79	1	76198	2363	77001	2621	258	2
BYJ 203	335	2	76194	2149	76356	2308	159	1
BYJ 215	429	1	76210	1217	76301	1238	21	2
BYJ 225	98	Depot	76184	257				
BYJ 240	12	Depot	76195	2102	76336	2370	268	1
BYJ 321	289	1	76198	1471				
CCL 027	24	Depot	76196	2129				
CCL 114	1379	Depot	76198	2058				
CCL 132	840	Depot	76210	2732				
CCL 238	278	Depot	76205	2706	77138	2888	182	-
CCL 252	6	1	76204	1199				
CCL 272	3	1	76198	2769	77026	2905	136	1
DUX 012	472	2	76205	1548	76245	1548	0	2
DUX 017	10	Depot	76208	1413				
DUX 050	3	2	76205	1508	76247	1526	18	1
DUX 056	138	1	76191	1388	76265	1437	49	1
DUX 088	389	Depot	76194	1356	76237	1358	2	2
DUX 089	148	2	76191	1498	76317	1504	6	2
PS 009	540	Depot	76210	2816	76293	2865	49	Depot
PS 014	132	Depot	76205	3161	76313	3174	13	1
EWC 001	54	Depot	76212	608				
AFO 010	344	1	76237	1541	76327	1558	17	Depot
AFO 020	30	1	76219	1675	77063	1781	106	1
AFO 028	11	1	76236	1566	77017	1618	52	1
AFO 035	390	Depot	76216	1941	77125	2284	343	1
AFO 043	1910	1	76218	5				
AFO 047	439	2	76214	2261				
BYJ 085	558	1	76231	1777	76279	1778	1	2
BYJ 087	153	1	76215	2419	77138	2845	426	-
BYJ 170	658	2	76217	1956	76338	2108	152	Depot
BYJ 178	355	1	76219	2012	77063	2170	158	Depot
BYJ 185	672	2	76240	1952				
BYJ 207	163	1	76222	1807	76301	1840	33	2
BYJ 251	149	2	76219	2459	77104	2652	193	1
BYJ 280	83	Depot	76226	1683	77125	1936	253	-

KT-73 MOCK WARRANTY UNITS
(continued)

SERIAL NUMBER	PRE-REPAIR TBO	REPAIR CATEGORY	DATE SHIP	ETI OUT	DATE RETURN	ETI IN	POST-REPAIR TBO	CATEGORY
BYJ 304	10	Depot	76229	1368				
BYJ 307	3	2	76225	2058	76275	2060	2	2
BYJ 323	19	2	76239	1235	76286	1249	14	2
BYJ 328	20	1	76231	1576				
BYJ 345	27	Depot	76236	1635	76322	1692	57	1
CCL 361	123	Depot	76215	982				
CCL 369	257	Depot	76216	1854		1906	52	Depot
CCL 371	40	2	76225	2276	76275	2277	1	Depot
DUX 018	13	Depot	76224	1434				
DUX 039	127	1	76237	1259				
DUX 055	33	Depot	76239	1507	76279	1507	0	2
DUX 065	160	2	76238	1690				
DUX 070	71	Depot	76232	1320	77154	1454	134	-
DUX 088	2	2	76244	1399	76317	1483	84	2
DUY 016	294	1	76230	1188				
DUY 030	816	Depot	76240	1095				
DUY 056	34	1	76217	1061				
EWC 023	56	Depot	76224	457				
PS 005	185	1	76232	2752				

Pre-repair TBO = 61 units

Mean = 286.541

Variance = 127,831.186

Standard Deviation = 357.535

Post-repair TBO = 36 units

Mean = 94.806

Variance = 11,714.733

Standard Deviation = 108.235

LN-14 MOCK WARRANTY UNITS

SERIAL NUMBER	PRE-REPAIR TBO	REPAIR CATEGORY	DATE SHIP	ETI OUT	DATE RETURN	ETI IN	POST-REPAIR TBO	CATEGORY
187	1283	Depot	76008	2188	77046	2534	346	Depot
190	25	Depot	76055	886				
2005	141	Depot	76041	1701	77130	1792	91	Depot
2325	226	Depot	76027	1342	76350	1372	30	Depot
3004	343	Depot	76055	1779				
3019	292	Depot	76033	1843	77019	2016	173	Depot
3021	315	Depot	76050	565	76336	692	127	Depot
3042	20	RTOK	76041	943	76128	961	18	RTOK
3046	28	Depot	76055	1131				
3049	138	Depot	76019	955	76092	975	20	Depot
3078	255	RTOK	76050	1297	76191	1323	26	RTOK
3088	30	Depot	76056	810	77153	1060	250	-
3089	13	Depot	76035	1381	76322	1562	181	Depot
3096	246	RTOK	76023	964	76093	977	13	Depot
3107	87	RTOK	76016	1628	76219	1809	181	Depot
3123	219	Depot	76005	1809				
3163	666	Depot	76033	1144				
3180	31	RTOK	76044	835				
3182	26	Depot	76014	1471	76225	1644	173	Depot
3195	452	RTOK	76014	1217				
3231	77	Depot	76019	1219	77123	1486	267	Depot
3605	409	Depot	76029	1335	77130	1493	158	Depot
3613	24	Depot	76027	888	77094	1157	269	Depot
3615	16	Depot	76023	270	76191	310	40	Depot
3616	377	Depot	76034	1797	77094	1835	38	Depot
3644	26	Depot	76021	1256				
3651	195	RTOK	76048	1290				
10205	15	Depot	76050	1522	76288	1652	130	Depot
10215	584	Depot	76041	986	76099	994	8	Depot
196M5	160	RTOK	76019	508	76288	639	131	Depot
33038	934	Depot	76044	2104	76295	2386	282	Depot
33067	579	Depot	76012	1915	76264	1926	11	Depot
33078	70	Depot	76016	385	76127	401	16	Depot
33109	14	Depot	76014	1597				
33144	483	Depot	76030	1938				
33146	43	Depot	76009	1411	76204	1566	155	RTOK
33147	56	Depot	76030	1478	77094	1658	180	Depot
33153	123	Depot	76054	1497	77025	1553	56	Depot
33163	49	Depot	76048	971				
33169	71	Depot	76008	705				
33187	73	Depot	76034	1732				
33236	12	Depot	76027	1167	76336	1416	249	Depot

LN-14 MOCK WARRANTY UNITS
(continued)

SERIAL NUMBER	PRE-REPAIR TBO	REPAIR CATEGORY	DATE SHIP	ETI OUT	DATE RETURN	ETI IN	POST-REPAIR TBO	CATEGORY
33237	534	Depot	76055	1413				
53043	236	Depot	76006	1343				
103147	73	Depot	76034	841	76306	991	150	-
103148	7	Depot	76056	82				
103193	15	Depot	76030	1030	76322	1089	59	Depot
103198	107	Depot	76058	1477	77004	1564	87	Depot
103212	30	Depot	76058	1356	76204	1378	22	Depot
103220	7	Depot	76005	1057	76188	1145	88	RTOK

Pre-Repair TBO = 50 units

Mean = 204.7

Variance = 68,085.439

Standard Deviation = 260.932

Post-Repair TBO = 33 units

Mean = 121.97

Variance = 9142.843

Standard Deviation = 95.618

APPENDIX E

SURVIVAL RATES FOR
EXPONENTIAL FAILURE
DISTRIBUTIONS

SURVIVAL RATES FOR EXPONENTIAL
FAILURE DISTRIBUTION

	HOURS											
TBO	100	101-200	201-300	301-400	401-500	501-600	601-700	701-800	801-900	901-1000	1001-1100	1101-1200
150	.5134	.2636	.1353	.0695	.0357	.0183	.0094	.0048	.0025	.0013	.0007	.0003
175	.5647	.3189	.1801	.1017	.0574	.0324	.0183	.0103	.0058	.0033	.0019	.0011
200	.6065	.3679	.2231	.1353	.0821	.0498	.0302	.0183	.0111	.0067	.0041	.0025
225	.6412	.4111	.2636	.1690	.1084	.0695	.0446	.0286	.0183	.0117	.0075	.0048
250	.6703	.4493	.3012	.2019	.1353	.0907	.0608	.0408	.0273	.0183	.0123	.0082
275	.6951	.4832	.3359	.2335	.1623	.1128	.0784	.0545	.0379	.0263	.0183	.0127
300	.7165	.5135	.3679	.2636	.1839	.1353	.0970	.0695	.0498	.0357	.0256	.0183
350	.7515	.5647	.4244	.3189	.2397	.1801	.1353	.1017	.0764	.0574	.0416	.0324
400	.7788	.6065	.4724	.3679	.2865	.2231	.1738	.1353	.1054	.0821	.0639	.0498
450	.8007	.6412	.5134	.4111	.3292	.2636	.2111	.1690	.1353	.1084	.0868	.0695
500	.8187	.6703	.5488	.4493	.3679	.3012	.2466	.2019	.1653	.1353	.1108	.0907

$R(t) = e^{-\lambda t}$ where: $e = 2.718281828$

λ = Failure rate or $\frac{1}{TBO}$

t = Class (hrs) Upper boundary

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